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IDENTIFICATION OF SAMPLING SITES FOR WATER QUALITY MONITORING IN NARMADA BASIN (M.P.)

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ABSTRACT

Assessment of water quality conditions over a wide area with respect to time and space requires the monitoring activities to be carried out in a network The location of a permanent sampling station is probably the most critical factor in a monitoring network which collects water quality data. If the samples collected are not representative of the water mass, the frequency of sampling as well as the mode of data interpretation and presentation becomes inconsequential.

Besides the economic considerations, there are three levels of design criteria of sampling station location. The macrolocation deals with river reaches in the river basin, the microlocation deals with the location of outfalls or other specific features within a river reach and the third level deals with the representative location points within a river's cross-section. The Sharp's procedure which is widely used for selecting locations is used for locating sampling points in the Narmada river basin.

The sequential water sampling sites were identified in the search for a pollution source using four different criterias e.g. tributaries, BOD, NPK and Pesticides. Only four levels of hierarchy have been used in the study. However, it was found that for the detection of single pollution source, sampling stations of the seventh level of hierarchies should be used.

Each of the four networks presented namely tributary, BOD, NPK, and pesticides based differs somewhat but it share a common approach towards the selection of reaches in which to sample. It must be emphasized that locations of sampling stations determined are not to be strictly applied. Therefore, an engineering judgement is required to locate a monitoring site which satisfy most of the technical requirements while minimizing the financial requirements. It is suggested that the proposed monitoring network may be used as guidelines in pin-pointing the appropriate sampling sites.

Further, it is observed that the present monitoring sites being monitored under GEMS/MINARS are self-sufficient as far as the middle and upper basin is concerned. But it certainly needs

improvement in the downstream portion of the basin particularly for controlling the pesticides, nutrient related problems in the lower basin having very high pollution loadings of pesticides and NPK.

1.0 Introduction:

Assessment of water resources requires knowledge of both the water quantity and water quality processes. Water quality occurs as a result of various natural factors including the geology, topography, climate, and the hydrology of a region. It is also affected by activities of man as a secondary factor in its evolution. Water quality also evolves as a function of the natural hydrologic environment and man made causes. In this case, however, the impact of the society, especially as related to urbanisation and industrialisation, is a primary causal factor in the occurrence of water quality. Furthermore, the two processes, water quantity and water quality, are in continuous interaction, so that a proper evaluation of water resources both from technical and economical points of view, requires a full understanding of both processes.

Apart from considerations related to development of water resources there has been an increasing concern in all communities over the impact of water quality on public health and general environmental conditions. The largest area where environmental pollution appears is water resources. Water pollution not only results in significant economic losses but may also lead to life threatening levels depending on the type and intensity of pollutants. Consequently, besides project makers, the society itself stresses the need for a better understanding of how water quality characteristics evolve in space and time under natural and man made conditions.

The role of water quality, then can be described to be two fold 1) it is particularly significant in terms of pollution control and its consequences 2) it is one of the basic factors to determine the amount of available water that can be used to meet a specific demand.

Both aspects have technical and economical implications leading further to the role of water quality in the development and management of water resources in the broadest sense.

In the past, water quality problems were primarily considered within a single perspective where the basic issue was to ensure a desired quality in water supplied for community and industrial uses. The solution was then to test for the quality of available water and design treatment systems if found necessary. However, the problem has changed for the more complicated as the demands on water resources, coupled with man's effect on these resources, have increased. As a result the role of water quality has become more important than before, for a effect on general pollution, and environmental control has considerably increased. Consequently, water quality needs to be evaluated in a broader scope than it used to be in the past, as a significant characteristic of water resources.

It follows from the above discussion about the role of water quality that information on water quality processes is needed with respect to water resources management in general and to pollution control in particular. As in the case of water quantity, retrieved of such information requires collection of data which are to be further processed analyzed and evaluated.

The general trend upto present in water quality management has been together and use information on water quality variables for purposes of planning, design and operation of water resources systems and wastewater treatment. Thus, most attempts at procurement of information on water quality variables have been a problem, project, or rather user oriented (Word & Loftis, 1986, Harmancioglu et al. 1992)). Another trend that is becoming quite evident is the increasing concern in all communities over the impact of water quality variables on human health and life conditions. Thus, there is the need for a better understanding of how water quality processes evolve both in space and time under natural and man made conditions. This further indicates the need for better methods of extracting information from collected water quality data.

Considering these two trends, some researchers have recently put emphasis on broader needs for water quality management than its previously problem oriented character required (Harmancioglu, et al. 1992; Sanders et al., 1983). Among the broad needs is regulatory water quality management with special emphasis on design of monitoring networks and extraction of information from collected data. In particular water quality management practices are expected to delineate.

1. The general nature and trends in water quality

characteristics for a better understanding of these processes.

2. The effects of natural and man made factors upon the general trends in water quality processes;

3. The effectiveness of water quality control measures.

4. The compliance of water quality characteristics with established quality standards for eventual purpose of enforcing quality control measures.

Recently, considerable emphasis has been placed on the following equally important issues.

5. Environmental impact assessment to determine the effects of a particular problem or development.

6. Assessment of the general water quality conditions over a wide area or general surveillance.

7. Determination of mass transport in a river.

Furthermore, increased concern about water quality has also led to comprehensive research activities in water quality hydrology. The success of such activities depends to a great extent on data availability and procurement of information from observed values. With these basic requirements fulfilled, research on water quality processes will eventually lead to significant progress in the science of hydrology as well as in other related fields.

The crucial points in all of the above issues are evidently the availability of appropriate and adequate water quality data and the full extraction of information from available data which in the case of water quality variables are fairly costly and time consuming to obtain in short the solution to the above problems has two requirements.

1. Data on water quality and

2. Extraction of maximum amount of information from available data.

The treatment to these two issues, then has further implications, such as decisions to be made on which variables to observe and which time and/or space intervals to select. Once these problems are solved, both water quality monitoring and management practices may be evaluated in a broader scope than their specific problem oriented character requires while meeting individual project needs.

1.1 Complexity of water quality monitoring :

Water quality conditions over a large area (often defined by political boundaries) are the function of complex natural and man-made causes and of the resulting interactions in both time and space. Consequently, abstracting the essence of the water quality conditions at a reasonable cost is often very difficult. This difficulty is rarely conveyed to these responsible for establishing water quality goals or management strategies. As a result the information expectations placed on water quality monitoring are often far beyond the ability of the network to supply such information. The complexity of water quality and its measurement is simply not understood by the public, by public officials, or in many cases, by network designers themselves.

Whatever the specific purpose of monitoring may be, it must first be recognised that water quality monitoring is a highly complex issue. The complexity may be attributed to two factors:

1. Uncertainties in the nature of water quality and
2. Uncertainties in delineating a specific purpose for monitoring

Uncertainties in the nature of water quality are due to the two fundamental mechanisms underlying these processes; the natural hydrologic cycle and man made effects, which are often referred to as the 'impact of society'. Both of these mechanisms particularly the first one are affected by laws of chance so that the water quality has to be recognized as a random process by nature (Sanders et al.,1983). Monitoring activities then are required to reflect the stochastic nature of water quality to efficiently produce the expected information. This is why most researchers like Sanders et al.(1983) and Harmancioglu et al.(1992) specify the term 'monitoring' further to mean 'statistical sampling'.

Secondly, it is not quite easy to define a specific purpose for monitoring. The technical part of this problem is best described by Harmancioglu et al. (1992) as : 'Today.... we face water quality problems whose sources are diffuse, impacts subtle and solutions unproven'. Besides, specification of purposes is subject to social, economic and legal constraints, which are also subject to unexpected changes in time.

1.2 Significance of water quality monitoring :

As complex as it is water quality monitoring is also highly significant because it is our only means of being informed about water quality. Thus monitoring constitutes the link between the actual process and our understanding, interpretation and assessment of the highly complex phenomena. Therefore water quality monitoring is the most crucial activity on man's side with respect to all management and control efforts. Adequately accomplished monitoring may serve to increase our knowledge on water quality processes and hence reduce the uncertainties whereas results of poor monitoring practices may lead to erroneous interpretations and decisions (Harmancioglu and Alpaslan,1990).

For example, Harmancioglu et al. (1992) claims that 'we are not really sure of the cost-effectiveness of some of the program accomplished to date because of the lack of adequate monitoring of water quality in our streams, lakes, and estuaries'. According to Harmancioglu et al. (1992) our understanding of environmental processes and problems evolve quite rapidly, whereas monitoring systems develop at a slower pace, often becoming out of date with respect to recently emerging issues and purposes of water quality assessment. On the otherhand the decision making process in water quality management is highly sensitive to the reliability and accuracy of available data. Further unreliable data the misinterpretation of information they convey may lead to wrong decisions. This situation is apparently worse than taking no action at all. In such a case, 'the underlying data can be said to have a negative economic value' (Harmancioglu et al. 1992).

Water quality management may be defined as the effort by society to control the physical, chemical, and biological characteristics of water. The efforts are directed at controlling the impacts of society upon the quality of water. Water quality in the environment, however is the result of two primary casual mechanisms: (1) the activities of society; and (2) the natural hydrologic cycle. Therefore, water quality management must deal with both events though it attempts to control only one the activities of society. Both mechanisms may be described as stochastic processes in that each, to some degree, is governed by the laws of chance. Thus, water quality, from a broad management perspective, can be considered a random variable.

Only recently has the random nature of water quality been recognised as having a large influence on the methods used to manage water quality, in general, and on the methods used to monitor (measure) water quality, specifically. Much of this recognition has been developed as the state-of-the-art in water quality hydrology and evolved the need to treat water quality monitoring as a statistical sampling process has been recognised (Ward and Loftis, 1983).

The purpose of this report is to present basic principles of water quality monitoring network design. The design technique presented acknowledge the practical limitations and objectives of current monitoring efforts while stressing the need to be more quantitative in the design process.

1.3 Definitions:

Water quality monitoring is the effort to obtain quantitative information on the physical, chemical, and biological characteristics of water via statistical sampling. The type of information sought depends upon the objectives of the monitoring network. Objectives range from detecting stream standard violations to determining temporal water quality trends.

The word "monitoring" in the strictest sense, implies watching the ongoings of water in order to ensure no laws or rules are violated. This connotation, while relevant to some objectives, has, in general, been lost since "water quality monitoring" refers to most types of water quality sampling or measurement.

As the word "monitoring" has taken on a different meaning when used to refer to water quality measurement, so has the term "network" taken on a meaning beyond the strict definition of the word when referring to water quality monitoring. As used here "network design" means determining the placement of sampling points, the calculation of sampling frequencies, and the selection of water quality variables to. measure in a hydrologically and statistically sound manner. Thus, network design relates more to the statistical and hydrological design of a water quality monitoring program than to the procedures used to collect samples, perform laboratory analyses, etc.

1.4 Assumptions:

Due to the above mentioned complexity, the network designer must clearly understand and define information objectives. Within the requirements for right which are implied by the information objectives, assumptions are made to reduce problems to a level where practical solution methods are available. The number and type of simplifying assumptions made or permitted depend upon the purpose of the network. Thus, depending upon the assumptions made, there are many levels of design which could be applied. The text will point out the different levels of design that are created by making different types of assumptions.

One often makes assumptions in water quality monitoring network design without realising it. For example, analysis of past data from an area for network design purposes must often be based on the assumption that the data actually represents the state of water quality in the field. Similarly, use of the normal distribution statistics assumes that the water quality variable is normally distributed.

Assumptions in network design are made relative to applicable statistics, water quality hydrologic principles, information utilisation and economic constraints. A designer weak in a particular area tends to make more assumptions in that area, whether consciously or unconsciously. The number, type and magnitude of assumptions made (whether explicitly or implicity) often causes considerable concern among designers and managers of networks. Designers, well versed in water quality hydrology, are more interested in removing water quality assumptions via water quality modelling or advanced statistical analyses while managers are more concerned with the economic assumptions involved. The public wants sound data and information and seldom understands the need for any assumptions. Striking a balance is often difficulty but is a goal for which all designers should strive.

1.5 Scope:

Given the complexity of water quality monitoring network design and the resulting use of assumptions, it is easy to see how 100 different designers could develop 100 different designs for the same area. There is a definite need to begin to develop water quality monitoring network design procedures, or principles, that can be generally regarded as valid by most designers. Inspite of this need, much of the literature on water quality network design has ignored the fact that there are some basics that all designers may rely upon.

The network design principles reviewed presented in the report cover the basics and some of the refinements that the authors have researched over the years., However, in a field as poorly defined as water quality monitoring network design, the basic principles presented herein must currently be considered more as guides than as widely agreed upon procedures. Hard-and-fast rules in such a complex area are difficult to develop.

Since the design techniques chosen depend upon many factors, the designer must be much more rational and thorough in approach selection to network design and consequently, more quantitative. Currently, the ability to select appropriate design procedures is as much as it is a science.

2.0 Review of literature in water quality network design:

The first data collection procedures for water quantity foresaw the gauging of major streams at potential sites for water resources developments. the approach in initiating water quality observations has been practically similar, namely, to collect data at potential sites for pollution problems. Consequently the early water quality monitoring practices were often restricted to what may be called 'problem areas' covering limited periods of time and limited number of variables to be observed. Basically these practices can be described to be problem, project or user oriented.

Recently, however, water quality related problems have intensified so that the information expectations to assess the quality of surface water have also increased. Thus, the problem or project-oriented monitoring practices of a limited nature can no longer meet the diverse needs for water quality data. The results have been an expansion of monitoring activities to include more observational sites and larger number of variables to be sampled at smaller time intervals. These efforts have indeed produced plenty of data; yet they have also raised the question whether one 'really' needs 'all' these data to meet information requirements. This question has recently become a serious issue, especially after it is shown by data analyses that water quality samples are often 'messy'.

The above considerations have eventually led to the realization that a more systematic approach to monitoring is required. Following up on this need, practitioners (monitoring agencies) and researchers have proposed and used various network design procedures either to set a network or to evaluate and revise an existing one.

Current methods of water quality monitoring network design basically cover two steps: first, the description of design considerations and second , the actual design process itself. Researchers emphasize the proper delineation of design considerations as an essential step before attempting the technical design of the network. This step is to provide answers to questions of why we monitor and what information we expect from sampling water quality. In otherwords, objectives of monitoring and information expectations for each objective must be specified first . Various objectives or goals for monitoring have been proposed up to date by different researchers (Ward and Loftis, 1986; Sanders et al. 1983; Whitfield, 1988; Langbein, 1979). Harmancioglu et al.(1992) have identified short term and long term goals of monitoring. The former is based on control strategies including prevention and abatement for purposes of assuring compliance with effluent and in-stream standards. Long term goals are related to planning and management purposes and cover the assessment of both the trends in water quality and the consequences of control measures.

In practice, the definition of objectives is not an easy task since it require the consideration of several factors, including social, legal, economic, political, administrative and operational aspects of monitoring goals and practices. Therefore, the first step in the network design i.e. the delineation of design considerations inevitably includes assumptions and subjective views of designers and decision makers no matter how objectively the problem is approached. In this case design considerations are often presented as general guidelines, rather than fixed rules to be pursued in the second step of actual design process (Sanders et al.,1983). Recently, researchers have stressed the need for clear and objective definition of these guidelines since design considerations actually setup the boundary constraints(e.g. social, legal, budgetary and /or operational constraints and information expectations) for the realization of the second step of actual design.

The technical design of monitoring networks relates to the determination of :

1. Sample sites;
2. Sampling frequencies;
3. Variables to be sampled and
4. The period of duration of sampling.

It is only at this actual design phase that fixed rules or methods are proposed. Current literature provides considerable amount of research carried out so far on the above mentioned four aspects of the design problem. One may refer to Sanders et al. (1983), to Whitfield (1988) for rather thorough survey of research results and practices on the establishment of sampling strategies with respect to these factors.

Basically, designers and researchers recognize water quality monitoring as a statistical procedure and address the design problems by statistical methods. Ward and Loftis (1986) stress that information expectations from a monitoring system must be defined in statistical terms and these 'expectations are to be in line with the monitoring system's statistical ability to produce the expected information'. This implies that one can infer on the types of data needed to perform statistical methods which in turn, will eventually lead to the expected information. Then the selection of sampling strategies (sampling sites, variable, frequencies and duration) can be realized by starting off with such statistical approach (Ward and Loftis, 1986; Sanders et al.,1983; Harmancioglu et al., 1992).

Monitoring networks are expected to reveal three basic statistical characteristics of water quality : means, extremes and changing water quality conditions (or trends). Designers point out that a network which is highly intense with respect to time and space is required to detect extremes with confidence (Harmancioglu et al., 1992; Sanders et al., 1983). However, such a design on a routine basis is pretty costly so that networks which reliably detect means and trends are more preferred (Ward et al, 1979). Yet there are also researchers who argue that modern information technology and electronic engineering provide the means of revealing more variability in the behaviour of water quality processes including the extremes (Beck and Finney, 1987). The current methods used in the technical design of monitorring networks can be summarized with respect to the four basic factors of sampling sites, sampling freqiencies, variables, and duration of sampling. In the present study, only the selection of sampling sites is reviewed.

2.1 Selection of Sampling Sites

If the intent of sampling were to study a limited portion of a river, as required to discover the immediate downstream effects of a given discharge (synoptic surveys), the placement of sampling transects might not be too critical to the generation of information descriptive of the reach in question (Sanders et al., 1983). However, when the intent of sampling is to monitor entire rivers or river basins any sample taking must be preceded by a thoughtful selection of reaches in the river basin to be sampled.

The water quality of a river reflects natural background conditions and the wastes it is required to carry. Because both conservative and non conservative pollutants are added to a stream along its entire length, water quality varies along the entire length also. It would be unrealistic to expect that a few water samples drawn at will could adequately characterise spatial and temporal variations in the stream. Nor would it be realistic to expect that samples drawn from a particular reach could be used to infer anything beyond local conditions, except with caution.

In recent years, the emphasis on water quality management shifted from the maintenance of stream standards to the maintenance of effluent quality. Stream standards expressed as limits not to be exceeded may be easily violated, especially if monitoring data used to indicate need for enforcement are collected intermittently rather than continuously. For many of the water quality variables which could be measured as indicators of stream quality, continuous monitoring is either not possible, not feasible, or not affordable. Two important complications accompany intermittent monitoring. One can not be sure that what appears to be a violation is not really a random rather than a continuous event. Secondly, it is difficult to identify a violator when only instream data are available. Furthermore, one must determine whether an apparent violation is an artifact of a sampling location wherein measurements have been taken close enough to a discharge point so that the discharge has not been able to disperse sufficiently within a mixing zone (Sanders et al., 1983).

A shift in emphasis from limitations on stream quality to limitations on effluent quality shifts in stream monitoring objectives from detection of stream standard violations to assessment of overall trends in water quality. This shift in objectives places enormous demands on a water quality monitoring network. To perform at the expected level, the network must be capable of characterising trends which in turn enable assessment of the effectiveness of abatement programs and determination of needed future abatement measures with in the entire river basin. To these ends water quality trend analysis should not be undertaken to find "critical quality points" or points having a high probability of stream standard violation to sample, but to identify sampling station locations which will yield information characteristic of reaches of the river and in composite with the other stations will yield information characteristic of condition of the river system in general. Monitoring to detect fugitive discharges or to identify specific violators is an important subject in its own right (Sharp, 1970) but is beyond the scope of this study.

Basic approaches to identifying macrolocations include one based upon percentage areal coverage and the second based upon the density of population is considered to correspond to the likelihood of polluting episodes and overall discharge of pollutants. Sanders et al., (1983) selected sampling station sites as a function of possible stream standards violations or as a function of stream segments below outfalls. Ward (1973) placed sampling stations at critical quality points in reference to each major source of pollution. In the percentage areal coverage approach stations are placed systematically to generate data on water quality in the entire river basin, an approach which lends itself to characterizing trends.

Sampling station locations for some monitoring programs (Sanders et al., 1983) were selected by finding points along the length of a stream at which various water quality variables of interest have been shown by experience to be approximately homogeneous in the cross section.

Some sampling programs generate data of questionable value because their sampling station locations were selected without reference to the spatial distribution of waste inputs. When an attempt is made to relate station density to some measure of population density such as placement of outfalls, the methods prescribed lack quantitative guidelines and by default become highly subjective. Budgetary constraints and limited availability of manpower usually dictate an arbitrary and inadequate sampling frequency. Consequently, current sampling programs may not provide information representative of the stream (along its length as well as in the cross section) and the sampling frequency may not be sufficient to detect average quality and to detect trends.

Samplers often draw samples at bridges or other sites which give convenient access to the river, without there necessarily being any relationship between sampling site and sources of stream pollution. In such a case sampling station location has been considered minimally. When the importance of sampling station location is recognized, it is often expressed by finding reaches along the length of the river which are judged by some criterion to be completely mixed in the cross section. While sampling in these reaches is greatly simplified, a single grab sample is presumed to be representative of the entire cross section, there still is no clear relationship between sampling site and sources of pollution. A zone of complete mixing (if such can in fact exist, other than in relation to a specific discharge) may not be found for many miles below an outfall, at which point one is hardly find a valid means by which to relate concentrations and water quality variables at the sampling site with specific conditions upstream.

Another approach is to designate sampling sites according to some logical basis : for example, to concentrate sampling near known sources of pollution. While this approach may come closest to generating data which reflect the quality of a stream as it varies with longitudinal position, it will nevertheless reflect bias unless a rational systematic procedure for designating sampling stations is employed.

Many authors have presented methods of characterizing a stream network. Perhaps the best known of these is Horton (1945) who defined strem order by designating the smallest unbranched tributary in the headwaters of a system as first order, a stream made up only of first order tributaries as second order; a third order stream as one in which all tributaries are of second or first order, and so on.

Sharp (1970) points out that Horton's ordering may be considered a measure of the uncertainty associated with locating the source of a pollutant detected at the outlet of a network. Shreve (1967) described a procedure which which used the number of tributaries or sources in a network to assign magnitude to individual sections or links, where a link is a section of channel that starts at a point termed the source and ends at a point termed the fork or junction. Sharp (1971) employed this system to describe the design of a river basin monitoring network intended for use in identifying the source of a stream standard violation. This approach is intended to locate possible sources of pollutants by analyzing a trade-off between sample source uncertainty and sampling intensity. Later, Sanders and clarkson followed up on Sharp;s procedure (Sanders, et al., 1983; Trich and Male, 1984).

Spatial design of water quality networks is also attempted by regression techniques. Trich and Male (1984) propose a multivariate regression model where the correlated regression coefficient of determination between sampling stations is considered as a measure of monitoring precision. The monitoring precision changes with the addition or deletion of some number and location of stations within a basin. Whitlatch (1989) examines the spatial adequacy of NASQAN water quality data by testing the differences between two sample means as a direct method and then by regression analyses between water quality variables and basin characteristics. Harmancioglu and Alpaslan (1992) applied the entropy principle for temporal and spatial features of network design which can be applied only after some necessary prior information is collected to apply the statistical techniques.

Some researchers stress the use of optimization techniques in selection of both sampling sites and sampling frequencies (Reinelt et al., 1988; Palmer and MacKenzie, 1985; MacKenzie et al., 1987; Dandy and Moore, 1979). such design procedures, two requirements are expected to be fulfilled by the network: cost-effectiveness and statistical power. The later is often investigated by analysis of variance (ANOVA) techniques, and optimization methods are used to maximize the statistical power of the network while minimizing the costs.

3.0 Description of Study Area:

The Narmada river is the fifth (comments from CWC) largest and probably the holiest of the rivers of India. Archaeological investigations have revealed human habitations along its banks even earlier than 5000 B.C.. The rich history along its course in the ancient and medieval times amply demonstrates the importance of the Narmada.

The Narmada river rises from a 'kund' in Amarkantak in Shahdol District of Madhya Pradesh (comment from CWC). The actual source is a small pond surrounded by a group of temples namely Pataleshwar, Machendranath, Triyathan and Keshavnath. After its origin Narmada flows mostly westward along an abnormally straight course. The river travels a distance of 1312 km before it falls into Gulf of Cambay in the Arabian sea near Bharuch in Gujrat. The first 1079 km are in Madhya Pradesh. In the next length of 35 km, the river forms the boundary between the states of Madhya Pradesh and Maharashtra. In the next length of 39 km it forms the boundary between Maharashtra and Gujrat. The last length of 159 km lies in Gujrat (Fig. 1).

The river flows most east to west through hill ranges upto Mahadwani where it is joined by an important tributary Silgi on its right bank. Thereafter it flows north to south upto Mandla where it takes a 'U' turn and flows south to north upto Narayanganj and then south east to north west upto Jabalpur. At Jabalpur the elevation is about 500 metre msl. The narrowest part of the basin is between Niwas and Kedarpur which is about 50 km wide.

At Jabalpur the river falls through a height of about 9 metre and enters the narrow gorge of marble rocks. The narrowest portion of the gorge is at Bandarkud, which translates to Monkey's Leap. Thereafter, it enters a great narrow elongated trough running east to west, with a slight inclination towards the south, till it drains into the Arabian sea at the Gulf of Khambat near Broach in Gujrat.

Narmada basin has elongated fern leaf like shape. The basin is broadly divided into upper, middle and lower sections. The Narmada Tribunal has listed 8 major tributaries on the right bank and 11 on the left bank. Narmada is a interstate river. The total

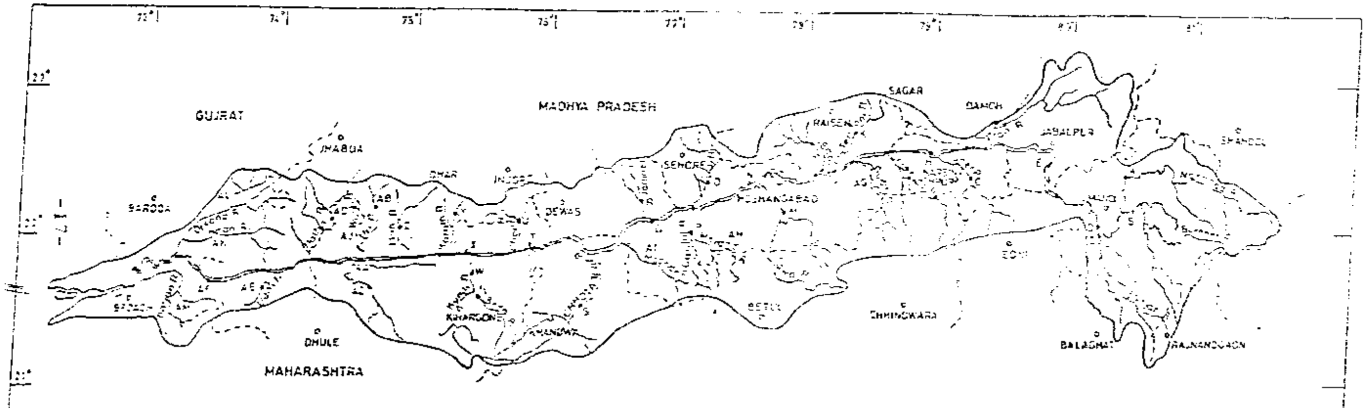

FIG. 1 MAP OF NARMADA RIVER BASIN

water availability of the river is estimated as 28 MAF. Madhya Pradesh, Gujrat, Maharashtra and Rajasthan shares 18.25 MAF, 9.00 MAF, 0.25 MAF and 0.50 MAF respectively.

3.1 Soil Type:

In the upper basin, majority of the soils are characterised by shallow black soils (stochrepts and storthents). These soils are the erosional products of trap basalts. The black soils are rich in smeclite clays having a high water holding capacity. These clay lattices expand when they absorb water and thus reduce the water drainage. The organic matter is generally less than 5% in black soils. The black soils in the upper basin is generally in-situ or colluvial. These soils are often inter-spread with red sandly or lateritic soils. The profile is generally shallow and mainly covers the hill tops and plateau regions. The red soils are the result of intense chemical leaching of basalts where by all the minerals in the rock are leach out except the oxides of silica, iron and aluminium. Due to intense leaching these soils have a reasonably good drainage but lack nutrients essential for plant growth.

The soils in the Vindhyan and Satpura plateau region of the middle basin range from shallow black soil (ustochrepts) with intrusion of medium black soils (pellusterts and chromusterts). Around Hoshangabad, recent alluviums with varied thickness can be witnessed. These soils are extremely fertile and supports cotton, jawar and wheat.

In the lower part of the basin the major soils of the valley and southern plateau are medium deep black soils. On the other hand mixed red and black soils occur in the northern plateau. In the mouth of the Narmada, pliocene rocks along with recent alluviums is seen. These alluvial soils are mostly sandy loams with good drainage. They are extremely fertile and support good crops.

3.2 Climate:

Narmada basin experiences three marked seasons - summer (March-May), rain (June-September) and winter (October-February).

The basin falls in the tropical region and is under the influence of the south-west monsoon. However, short spells of seasonal deviation in climatic condition are often noticed and are caused due to various reasons, like Orography, vegetation pattern etc. The normal rainfall of the basin is about 1180 mm.

The temperature is maximum in the month of May and minimum in January. Generally, the upper Narmada basin record lower temperatures as compared to the middle basin. In the lower section of the basin, influence of the sea is prominent and the temperature, though lower than the middle basin, is higher than the upper reaches of Narmada river. The variation in relative humidity between upper, middle and lower sections of the basin is not very pronounced.

3.3 Geology:

Along the Narmada valley several patches of ancient sediments have been deposited which contains ancient remains of animals. These fossils are similar to those found along the tracts of Tapti river. Such similarity probably suggests that even about 3 million years ago Narmada and Tapti were confluent and the separate fate of these two rivers was decided by earth movements in later (comments from CWC). The Behraghat falls of Narmada, near Jabalpur was probably created during one such movement which appears to be a recent one.

The Archaean group of rocks in the Narmada basin is represented by the Chilpighat series. These rocks wedge in at the eastern and between the Vindhyans and granitic gneisses and expand in the Narmada valley in strips. These Dharwadian rocks consisting mainly of quartzites, felspathic grits, shales and slates with intercalated traps occur in Balaghat, Chindwara, Jabalpur districts of Narmada valley. In Jabalpur area the series is distinguished by perfectly crystalline dolomatic limestones. The famous "marble rocks" of Jabalpur belong to this series.

On the upturned edges of the Archaeans, the Cuddapahs were deposited and are represented by Bijawars in the Narmada Valley. The Bijawars occurs in the series of out crops extending from Bundelkhand to the south of Narmada and has thickness of less than 240 m at some places. These rocks are generally characterized by quartzites, sandstones and sometimes conglomerates. Bijawars are found in Dhar and Jabalpur districts. In Jabalpur, however, Bijawars are represented by somewhat different rock assemblages like phyllites, mica schists, calcitic and dolomatic marbles. There is, however, some controversy over the age of the rocks and some geologists feel that they are older than Cuddapahs and should classified along with upper Archaeans i.e. Dharwadian rocks.

The Cuddapahs were succeeded by rocks of Vindhyan system after a time interval marked by earth movement and erosion. The Vindhyan rocks characterised by Bhander sandstones, shales, limestones and Ganurgarh shales are exposed in the north of Hoshangabad town and extends upto Bhopal. Between Dewas and Khandwa in Parnakheri thick vindhyans are exposed along the banks of Narmada mainly characterized by Bhander group of rocks and unclassified upper Vindhyans.

Thick Gondwana sediments are found near Jabalpur, Rewa Panchmari etc. The Gondwana formation ended in Cretaceous era i.e. about 135 million years ago. The end of cretaceous was marked by enormous lava flows which spread over vast areas of central and eastern India. Thick lavas of basaltic composition are found in Khandwa, Khargone, Dhar, Dhuk area till practically upto the lower Narmada region. The interesting geological episode in the Narmada valley are the lameta beds, which occur in Lameta ghats near Jabalpur. The Lameta beds represent the fluviatile or estuarine deposits just below the trap basalts.

3.4 Landuse Pattern of the Basin :

Landuse pattern is a fairly useful indicator in understanding the environmental set up, socio-economic status, infrastructural facilities, soil type and climatic conditions of an area. In the Narmada basin, the landuse pattern of Madhya Pradesh has a significant importance, mainly because of more than 87% of the basin area falls in this state, followed by Gujarat (11.4%). An insignificant portion of Maharashtra 1.5% also falls in the Narmada basin. Table 1 presents the statewise landuse pattern of the Narmada basin (CPCB, 1994).

Table 1. The General Landuse Pattern of Narmada Basin.

S. No.	Particulars	Madhya Pradesh	Maharashtra	Gujarat	Total
		(Area in lakh Ha.)			
1	Total basin area	85.86	1.54	11.4	98.8
	% of total area	87%	1.5%	11.5%	100%
2	Forest Area	29.37	0.69	1.7	31.76
	% of basin area	29.7%	0.69%	1.7%	31.09%
3	Unavailable for Cultivation	6.63	0.05	1.33	8.01
	% of basin area	6.7%	0.05%	1.3%	8.05%
4	Cultivable area	49.84	0.8	8.37	59.01
	% of the basin	50.44%	0.81%	8.47%	55.72%
5	Net sown area	36.81	0.8	7.38	44.99
	% of total cultivable area	62.37%	1.35%	12.50%	76.22%
6	Gross sown area	39.22	0.87	7.53	47.62
7	Net irrigated area	1.3	0.87	7.53	47.62
	% of total	2.20%	0.08%	1.4%	3.68%
8	Gross irrigated area	1.32	0.08	0.94	2.34

4.0 Pollutant load and Water Abstraction in the Narmada Basin:

4.1 Use of Chemical Fertilizers :

To increase the agricultural production to meet the growing demand, the use of chemical fertilizers have become common. Most commonly used fertilizers are Urea, DAP, SSP and Muratae of Potash. The fertilizers hydrolyse in soil and supply the essential nutrients to the plants. However, there is an apprehension that soil may loose its sorption capacity due to the repeated application of chemical fertilizers and finally may loose its fertility. The other problem related to the use of chemical fertilizers is the pollution of surface and ground water. A part of the fertilizers that is applied to agricultural fields gets washed off due drainage and runoff and may pollute the surface water. The leaching of nitrites to the ground water from fertilizers have also been reported in various parts of the world. Nitrites causes a disease known as Mathemeloglobenamia, causing damage to central nervous system. However, in India the application rate of fertilizers is low and cases of fertilizer related pollution, of either surface or ground waters have been reported. It is revealed that the use of Nitrogen fertilizers are most common in the basin. The use of phosphorous based fertilizer is more than that of Potash based fertilizers. The total application of N, P & K fertilizers in all the districts of Narmada basin is about 4.6 lakh tonnes, out of which about 58% is Nitrogenous, about 33% is phosphorous based and about 9% is Potash based. Seasonwise Consumption in the Narmada basin is given in Table-2 (CPCB, 1994).

Use of pesticides for pest control is common practice in agriculture. In earlier days Neem extract or Tobacco water was used for pest control but with the advancement of chemical industries, more effective pesticides are in use. The total pesticide consumption in some of the districts in Narmada basin is given in Table-3 (CPCB, 1994). In Narmada basin the Organo-phosphate pesticides are more common than the Organo-Chlorides. The application rate of pesticides in the basin is quite low and range between 0.7 to 0.01 kg/ha/yr for Organo-Chlorides. The total application rate for all type of pesticides ranges between

TABLE - 2

SEASONWISE CONSUMPTION OF N P_2O_5 AND K 20 1990-91 (QUANTITY IN TONNES)

S.No. Zonal/State/ District	Kharif 1990 N	P205	K20	Total	Rabi 1990-91 N	P205	K20	Total	Total 1990-91 N	P205	K20	Total
A. MADHYA PRADESH												
1. Balaghat	4132	2428	204	6764	815	490	32	1337	4947	2918	236	8101
2. Betul	3414	2207	326	5947	3725	1801	475	6001	7139	4008	801	11948
3. Chindwara	3634	2064	318	6061	3450	1283	266	4999	7084	3347	584	11015
4. Damoh	615	294	16	925	1798	1687	36	3521	2413	1981	52	4446
5. Dewas	4436	3913	283	8632	8775	3741	170	12686	13211	7654	453	21318
6. Dhar	13768	9535	3374	26677	8547	4947	588	14082	22315	14482	3962	40759
7. Hoshangabad	5803	737	220	*13850	17051	10440	1050	28547	22044	18177	1270	42397
8. Indore	8758	6940	749	10456	10700	5454	249	10493	19548	15403	998	35949
9. Jabalpur	2782	1153	121	4656	7576	5323	322	13231	10358	7276	453	18087
10. Jhabua	4373	1208	148	5729	1508	506	53	2157	5971	1714	201	7888
11. Khandwa	9810	5176	4588	19664	4098	2587	2354	9039	14538	7763	6942	20243
12. Khargone	14800	7061	1499	23360	6127	2872	791	9790	20927	9933	2290	33150
13. Mandla	1205	230		1453	398	236	18	652	1603	466	18	2087
14. Narsingpur	1614	1354	40	3038	5889	5756	351	11996	7503	7110	391	15034
15. Rajnandangaon	9748	2500	904	13152	920	704	513	1837	10368	3208	1417	14980
16. Raisen	1532	1129	13	2674	7600	6369	141	14110	9132	7498	154	16784
17. Sagar	2140	1892	71	4106	5775	5533	278	11308	7918	7145	349	15412
18. Sehore	4108	3199	175	7482	4525	3522	198	8345	8633	6821	373	15827
19. Seoni	1153	675	96	1924	632	472	50	1154	1785	1147	146	3078
20. Shahdhol	403	398	7	808	1123	1070	19	2212	1526	1468	26	3020
Total				176453				174095				350530
B. MAHARASHTRA												
1. Dhule	21067	7099	4899	33065	7714	4885	2918	15517	28781	12984	7817	49482
C. GUJARAT												
1. Baroda	16023	6979	1650	24652	13805	3165	1048	18018	29828	10144	2698	42670
2. Broach	5292	2134	2349	9775	4664	1873	1483	8020	9956	4007	3832	17795
Total				34427				26038				60455
G. Total				244815				215650				460455

TABLE- 3
USE OF PESTICIDES/BIOCIDES IN NARMADA BASIN

Sl.No.	District	*Consumption, Tonnes/Year*				*Application Rate Kg/Hect of Net Sown Area*				*Application Rate Kg/Hect of Gross Sown Area*			
		O.P.	*O.C.*	*Others*	*Total*	*O.P.*	*O.C.*	*Others*	*Total*	*U.P.*	*O.C.*	*Others*	*Total*
1.	Balaghat	32.2	4	-	32.24	0.19	0.12	-	0.21	0.09	0.01	-	0.1
2.	Betul	13	4.8	-	7.8	0.04	0.01	-	0.05	0.03	0.01	-	0.04
3.	Chhindwara	28.4	13.9	-	42.3	0.06	0.03	-	0.09	0.05	0.03	-	0.08
4.	Damoh	7.8	1.3	-	9.1	0.03	0.01	-	0.01	0.03	0.01	-	0.04
5.	Dewas	39.15	66.4	-	105.5	0.11	0.2	-	0.31	0.1	0.16	-	0.26
6.	Dhar	379	219	-	598	0.76	0.4	-	1.16	0.7	0.41	-	1.11
7.	Hoshangabad	305.0	175.1	4.1	48.5	0.69	0.4	0.01	1.1	0.56	0.32	0.01	0.89
8.	Indore	27.2	14.8	1.6	3.6	0.1	0.06	0.01	0.16	0.08	0.04	0.01	0.12
9.	Jabalpur												
10.	Jhabua	33.3	8.1	6.8	48.2	0.1	0.03	0.02	0.15	0.09	0.02	0.02	0.13
11.	Khandwa	194.9	16.6	-	211.6	0.45	0.04	-	0.49	0.41	0.03	-	0.44
12.	Khargone	101.3	14.2	-	5.5	0.16	0.02	-	0.18	0.15	0.02	-	0.17
13.	Mandla	2.4	7	-	2.47	0.01	0.02	-	0.03	0.01	0.01	-	0.02
14.	Narsinghpur												
15.	Rajnandangaon	43.7	1	-	44.7	0.09	0.01	-	0.1	0.7	0.01	-	0.71
16.	Raisen	48.5	23.2	-	1.7	0.19	0.05	-	0.24	0.11	0.05	-	0.16
17.	Sagar	69	14.8	-	3.8	0.14	0.03	-	0.17	0.13	0.03	-	0.16
18.	Sehore	89	31	-	120	0.25	0.1	-	0.35	0.22	0.07	-	0.29
19.	Seoni	15	2.7	-	18	0.04	0.01	-	0.05	0.04	0.01	-	0.05

O.P: Organo Phosphates
O.C: Organo Chlorides

1.1 to 0.02 kg/Ha/yr which is quite low even according the Indian standards.

4.2 Pollutant Load:

4.2.1 Pollutant loads from agriculture :

Portions of fertilizers and pesticides applied to the agricultural fields are washed away with agricultural return and surface runoffs. Nitrogen, Phosphates and Potash are the main types of fertilizers applied in the agricultural fields of Narmada basin. The nutrient load from the agricultural runoff primarily depends on the solubility of the concerned elements presents in the fertilizers. Phosphorous is sparingly soluble in water and therefore a maximum of about 5% is likely to dissolve in runoff water and carried to the water bodies. Potash and Nitrogen, on the otherhand is more soluble and therefore it can be assumed that about 10% of the total amount applied will be washed off through agricultural wastes. In the districts along the Narmada basin about 27000 tonnes of N is likely to be washed off. The estimated quantity of P and K runoff is about 8000 tonnes and 3000 tonnes respectively. The maximum contribution of N & P is from Hoshangabad district which uses maximum amount of these fertilizers. Khandawa contributes about 690 tonnes of Potash in the runoff.

The application rate of pesticides in the Narmada basin is quite low (CPCB, 1994). The basic problem with pesticides, especially the Organo-chlorides, is their prolonged residence in the environment. These pesticides are practically non degradable and therefore, retain their toxicity for long periods. Fortunately in the Narmada basin the use of Organo-chlorides are restricted and most of the pesticides applied to the crops belong to the Organo phosphate group, which has a lower residence time. The total amount of pesticide runoff is too low to cause any environmental problems. The estimated pollutant load by CPCB(1994) is given in Table-4.

TABLE -4
ESTIMATED POLLUTANT LOADS FROM AGRICULTURE (TONNES/YEAR)

S.No.	State/District	Estimated Pollutant Loads			
		N	*P*	*K*	*Pesticides*
A.	MADHYA PRADESH				
1.	Balaghat	494.7	145.9	23.6	1.6
2.	Betul	713.9	220.4	80.1	0.9
3.	Chhindwara	708.4	167.4	58.4	2.4
4.	Damoh	241.3	99.1	5.2	0.46
5.	Dewas	1321.1	382.7	45.3	5.3
6.	Dhar	2231.5	724.1	396.2	29.9
7.	Hoshangabad	2294.4	908.85	127.6	2.9
8.	Indore	1954.8	770.2	99.8	2.2
9.	Jabalpur	1035.8	363.8	45.3	0.25
10.	Jhabua	597.1	85.7	20.1	2.41
11.	Khandwa	1453.8	388.1	694.2	10.58
12.	Khargone	2092.7	496.7	229	0.6
13.	Mandla	160.3	23.3	1.8	0.12
14.	Narsinghpur	753.3	355.5	39.1	0.7
15.	Rajnandgaon	1036.8	160.2	141.7	2.2
16.	Raisen	913.2	374.9	15.4	3.6
17.	Sagar	791.8	357.9	34.9	4.2
18.	Sehore	863.3	341.1	37.3	0.6
19.	Seoni	178.5	57.4	14.6	0.9
20.	Shahdol	152.6	73.4	2.4	2.6
	Total	19989.3	6476.1	2082.2	70.07
B.	MAHARASHTRA				
1.	Dhule	2878.1	644.2	781.7	1.6
C.	GUJARAT				
1.	Baroda	2982.8	507.2	269.7	5.1
2.	Broach	995.6	200.3	383.8	7.8
	Total	3978.4	707.5	653.6	12.9
	G.Total	26845.8	7827.8	3517.5	84.57

4.2.2 Pollution load from Anthropogenic Sources :

Anthropogenic activity generates substantial amount of BOD. These activities include various associated human activities like cattle raising, animal husbandry etc., which is vital for human survival. The per capita daily generation of BOD equivalent due to the metabolic activity of human beings is about 100 gms. However, the same amount does not get carried away along with the runoff due to natural self purification. The digestion process starts right from the initial stages and some BOD gets removed. It has been assumed that the BOD loading of the streams due to human metabolism would average about 15/capita/day. It has also been assumed that a section of the rural population have some sort of latrine and other practice open air defection (OAD). The urban loading of BOD is definitely more than the rural load. The BOD loading from urban population varies with the public utilities available. It has been noticed that towns with organised water supplies and sewerage system, generate an average BOD of more than 50 g/capita/day. It has been assumed that urban agglomerations generate a load of 50 g/capita/day. The BOD equivalent through an adult cow is about 20 g and that of Buffalo is about 25 g or higher. Thus considering that some escape to drains, the total BOD loading of water bodies due to cattle will not exceed 15 g per day.

The generation of BOD from industries vary widely and depends on the industrial process and treatment accorded to the wastes. Wherever the data was not available, the loading was calculated on data provided by CPCB for similar industries located in the area.

The total loading is about 440000 kg/day, of which rural areas contribute about 58%. The urban agglomerations contribute about 36%. As the industrial development in the area is poor the contribution of industries to be total BOD is quite low and restricted to about 14%. Some pulp and paper industries and a few distilleries along the Narmada contribute the major BOD load. At the district level the highest BOD contribution is from Hoshangabad district and the lowest from Jhabua district. The domestic /municipal pollutant loads as estimated by CPCB(1994) are given in Table-5.

TABLE-5 : DOMESTIC/MUNICIPAL POLLUTANT LOAD IN NARMADA BASIN (BOD Kg/day)

S.No.	State/ District	RURAL Human Domestic	RURAL Cattle	RURAL Total	URBAN Human Domes.	URBAN Indus-trial	URBAN Total	Total for District
A.	MADHYA PRADESH							
1.	Balaghat	5295	2115	7410	NUC	14.3	14.3	7424
2.	Betul	5760	795	6555	3400	7.7	3407	9962
3.	Chindwara	7275	2340	9615	NUC	31.7	31.7	9646
4.	Damoh	840	345	1185	NUC	NIU	-	1185
5.	Dewas	8295	3240	11535	8000	NIU	8000	19535
6.	Dhar	110650	4560	15210	NUC	14.4	-	15224
7.	Hoshan-gabad	14220	7545	21765	15800	10800	26600	48365
8.	Indore	10140	1305	11445	NUC	NIU	-	11445
9.	Jabalpur	7620	5190	12810	99400	NIU	99400	112210
10.	Jhabua	240	1140	1380	NUC	0.22	0.22	1380
11.	Khandwa	11820	1215	13035	7250	15.68	7265	20300
12.	Khargone	27045	10170	37215	3500	6948	10448	47663
13.	Mandla	15300	9185	24435	3850	8.7	3858.7	28293
14.	Narsing-pur	10260	-	10260	3800	NIU	3800	10460
15.	Rajnandan gaon	1380	720	2100	NUC	5.4	5.4	2105
16.	Raisen	7515	3750	11265	NUC	NIU	-	11265
17.	Sagar	1665	705	2370	NUC	NIU	-	2370
18.	Sehore	7005	3225	10230	NUC	NIU	-	10230
19.	Seoni	3900	3240	7104	1900	1132	3032	10436
20.	Shahdhol	1230	705	1935	NUC	NIU	-	1935
B.	MAHARASHTRA							
1.	Dhule	4480	1965	6405	NUC	NIU	-	6405
C.	GUJARAT							
1.	Baroda	17700	2085	19785	NUC	1000	1000	20785
2.	Broach	16950	3120	16020	12600	NIU	12600	28620
	Total	34650	5205	35055	14000	1000	13600	47655
	G.Total	196554	64050	255795	159500	19977	179477	444596

4.3 Waste Water Disposal in Narmada Basin:

So far as human beings are concerned, majority of the water abstracted for use is returned as wastes and actual consumption amounts to only a small fraction of the total water. For industries, the amount of water consumption depends on the purpose for which the water is withdrawn. The boilers consume about 10% of the water and cooling process consume about 3 to 4% of the total abstracted water depending upon the cooling system. On the other hand, a major part of the water abstracted for irrigational purposes is consumed and only 15 to 20% of the total applied water is returned as wastes. The consumption of water in agriculture mainly depends on infiltration and evaporation and evapotranspiration. The plants themselves retain a small quantity of water. However, all the processes related to water abstraction, losses and consumption are a part of the hydrosphere cycle, suggesting that the total water in hydrosphere remain constant though it changes its phase or form.

The wastes generated mostly flows through various streams and meet the neighbouring water bodies. A portion is also lost from the surface runoff systems through evaporation and percolation. For example the waste water for irrigation is calculated based on the assumption that 20% of the applied water is returned as waste water through surface runoff. For the calculation of domestic waste water from rural and urban usage, two different sets of assumptions were made. In a rural environment a significant amount of water used is consumed through seepage, as most of the drains are natural channels. Therefore only 50% of water used for rural domestic purposes were considered as return water. In the urban agglomerations most of waste water flows through sewerages and therefore the losses due to infiltration and evaporation is negligible. Considering this, it has been assumed that about 80% of the water abstracted for urban usage returns to the surface water regime as waste water. 80% of the water abstracted for industrial usages has been assumed as waste waters.

About 50% of the waste water comes from irrigational fields and about 43% from rural and urban domestic wastes. The wastes from urban sources account for about 25%, whereas the rural population contribute only 18% of the wastes. It may be noted that though in the Narmada basin about 80% of the population is rural, the wastes from urban sources is about 1.4 times more than that of rural sources. On a district level, Hoshangabad contributes about 12% of the total waste water generated in the Narmada basin. Shahdol contributes a minimum of about 0.3% of the waste water to the Narmada basin.

4.4 Water Abstraction :

4.4.1 Water abstraction for Agricultural use :

Application of water in requisite quantities at the appropriate time is one of the most important aspects of agriculture. The function of soil moisture in plant growth is very important for healthy growth of crops and plants. The main functions of irrigation water are as follows :

- it acts as a solvent for nutrients. Water forms the solution of nutrients and this solution is absorbed by roots. This water acts as nutrient carrier.
- the irrigation water supplies moisture which is essential for the bacterial growth beneficial for plants.
- some chemicals present in soil react with water and the hydrolysed product nourishes the plants.
- Irrigation water dilutes the harmful salts and often washes them off.
- It softens the tillage pans.

Various crops require different quantities of water and any marked variation can spoil crops totally. In India a majority of the areas are irrigated by monsoon rains and therefore, the crop production largely depends on the vagaries of monsoon. The total annual abstraction from all sources for agricultural purposes is about 935 MCM out of which about 260 MCM (i.e. about 30%) is abstracted from canals. The maximum amount of water abstracted from canals for irrigation is in Khandwa district. In the basin about 69% of the water is abstracted for irrigation from other sources like ground water, tanks etc.

4.4.2 Water Abstraction for Domestic used :

Water is a basic requirement for human survival. Water is mainly consumed by human beings for drinking, bathing and cleaning purposes. The water consumption by population basically depends on availability and habit of the respective population. Since in rural areas the availability of water is poor and often a lot of effort is necessary to procure water in requisite quantities, the amount of water used per capita is quite low and varies between 202 and 30 litres per person per day (lpcpd).

On the other hand, water in the urban areas are available with relative ease and often a organised supply system exists. However due to high growth rate of urban population and lack of basic infrastructural facilities, the availability of water in urban agglomerations has become increasingly difficult. The average per capita consumption of water in well equipped urban agglomerations is likely to be about 250 to 300 lpcpd. However, in the Narmada basin, the per capita consumption of drinking water is not likely to exceed 150 lpcpd. The majority of the population in the Narmada basin is rural and their need for water is low. Total amount of water abstracted from the basin to meet the demand of the rural population is about 134 MCM per year. About 20% of the population in the Narmada basin reside in urban agglomerations and total amount of water abstracted to meet their demand is about 119 MCM per year, marginally lower than the rural population demand.

4.4.3 Water abstracted for Industrial use

The industrial development in the Narmada basin is poor and only a few districts house large and medium industries. However, no systematic data on the number of industries and the water abstracted by them is available. Only about 72 MCM of water is abstracted from Narmada basin for industrial purposes which is about 20% of the water abstracted to meet the demands of the rural and urban population.

5.0 Data preparation :

The districtwise pollution load as given in Table-4 and Table-5 was distributed among the various tributaries. The distribution of pollution load was made in proportion of the length of tributary passing through a given district. Following this procedure, the NPK, pesticides and BOD load contributed by different tributaries were calculated and given in Table-6.

Table-6. NPK, Pesticides and BOD load (Kg/day) in different tributaries of Narmada river basin.

S No	Name of the tributary	NPK-load (Kg/day)	Pesticides (Kg/day)	BOD-load (Kg/day)
1.	Narmada at Manot	177	0.11	9880
2.	Burhner	1760	3.12	12345
3.	Banjar	3961	7.45	10904
4.	Narmada at Mandla	56	0.03	3144
5.	Narmada at Jamtara	1391	0.85	38121
6.	Hiran	2786	0.49	78962
7.	Sher	1556	2.46	12195
8.	Narmada at Barman	449	0.27	2009
9.	Shakkar	1584	2.88	6388
10.	Narmada at Sandia	1622	3.01	6282
11.	Tendoni	1035	2.85	3565
12.	Barna	1631	2.49	5143
13.	Bagra Tawa	4121	4.63	18155
14.	Narmada at Hoshan-gabad	2883	1.89	11733
15.	Kolar	1856	0.90	5580
16.	Ganjal	1336	1.15	7083
17.	Narmada at Handia	4608	10.69	20653
18.	Jamner	1712	5.18	6977
19.	Chhota Tawa	5459	22.77	15950
20.	Narmada at Mortaka	2400	4.88	9228
21.	Choral	8220	6.14	14410
22.	Beda	1293	0.27	7982
23.	Kundi	2401	0.52	14823
24.	Narmada at Mandle-shwar	1330	0.27	8210
25.	Karam	1450	12.93	2404
26.	Man	2417	21.56	4006
27.	Narmada at Rajghat	2417	21.56	4006
28.	Uri	1933	17.23	3205
29.	Goi	1847	0.38	11403
30.	Hathni	1323	4.52	948
31.	Udai	4212	1.56	2287
32.	Narmada at Garu-deshwar	11701	15.51	20255
33.	Dudhi	1583	2.88	6388
34.	Morand	1922	1.70	8198
35.	Machak	1718	3.15	7926
36.	Wagh	967	8.63	1602
37.	Heran	2919	4.33	5731
38.	Orsang	5472	7.64	10811
39.	Karjan	2416	12.74	17058

6.0 Sequential Sampling plan for the Narmada River Basin :

A sequential sampling plan for locating water quality stations on river Narmada has been formulated on the basis of basin topography and pollution loadings using Sharp's procedure.

6.1 Sampling Sites Based on Number of Contributing Tributaries:

Fig. 1 shows the basin map showing the major contributing tributaries of the Narmada river. In this map some of the tributaries having insignificant contribution have not been shown. These have been dropped out while considering the whole of the basin.

Fig. 2 shows the numbering based on the tribuaries of the Narmada river following the Sharp's Criteria. The zero level hierarchy is always at the mouth link M_0 which is 83.

The major centroid where a first hierarchy station is to be placed, is located in that link whose magnitude is closest to :

$$M_1 = \left[\frac{N_0+1}{2}\right] \quad \text{-------------------(1)}$$

in which N_0 = total number of exterior tributaries which equal to M_0 the magnitude assigned to the outlet, M_1 = first-hierarchy link, and the squared brackets indicate that the enclosed value will be truncated to the integer value.

Using (1) and substituting N_0 = 83, the first-hierarchy sampling site is:

$$M_1 = \left[\frac{83+1}{2}\right] = 42$$

Therefore, the first hierarchy would be placed in link number 42. Because there is no link with this number the link closest in magnitude, link 43 is selected as the centroid. Once a link is specified, a sampling location is designated at its downstream junction. Further, each designated reach should be examined individually in light of accessibility, presence of zones of complete mixing or other existing unique conditions.

If the first-hierarchy link were erased, two systems

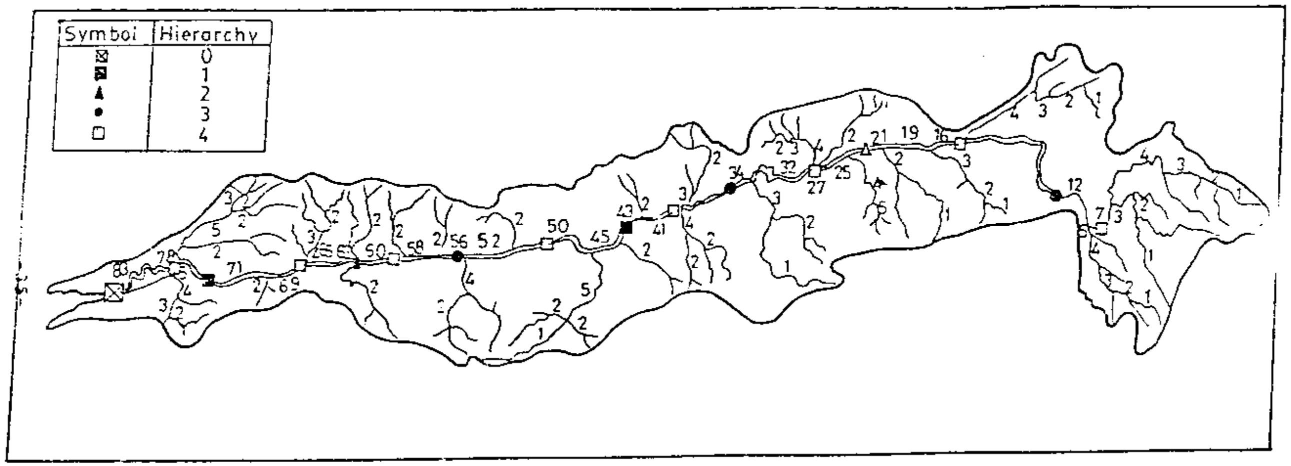

FIG. 2 NETWORK OF SEQUENTIAL MONITORING WATER QUALITY SITES ON THE BASIS OF TRIBUTARIES.

result which are approximately equal in magnitude. The upstream portion has a magnitude of 43 for which the centroid is :

$$M_{i+1} = [\frac{M_i + 1}{2}] \text{ ------------------- (2)}$$

$$M_2 = [\frac{43+1}{2}] = 22$$

Again, there is no tributary having link number 22 so the nearest in magnitude, link 21 is selected.

In Sharp's treatment of the downstream portion, one can either renumber tributaries, using the same procedure outlined above or the centroid may be found by selecting that link which is closest to either:

$$M_i' = [\frac{M_d - M_u + 1}{2}] \text{ ----------------- (3)}$$

or

$$M_i' = M_u + M_i' \qquad \text{ ---------------- (4)}$$

where M = magnitude of the link, i = hierarchy level, M_d = magnitude where the basin is divided on the down stream side, M_u = magnitude where the basin is divided on the upstream side, and M_i' and M_i' = alternative possible centroids.

In the present case M_u = 43, M_d = M_0 = 83, which gives M_2' = 20 and M_2' = 43 + 20 = 63. The reach of magnitude 63 is selected.

With the second hierarchy stations specified, third-hierarchy stations may be selected by a similar procedure. Using (2), in the upstream half the third hierachy stations are:

$$M_3 = \frac{21 + 1}{2} = 11$$

With no link numbered 11, the nearest link in magnitude would be selected which is 12.

Still in the upper half of the river network, a lower third hierarchy station should be specified. Using equations (3) and (4):

$$M_3' = \frac{43 - 21 + 1}{2} = 12$$

$$\text{or} \quad M_3'' = 21 + 12 = 33$$

Because there is link having been numbered 33, the nearest link 34 is chosen.

Similarly the third hierarchy stations in the downstream half may be determined using equation (3) and (4).

$$M_3' = \frac{63 - 43 + 1}{2} = 11$$

$$\text{or} \quad M_3'' = 43 + 11 = 54$$

As there is no link with 54, the nearest link 56 is selected. Further the third hierarchy station in the last portion is

$$M_3' = \frac{83 - 63 + 1}{2} = 11$$

$$\text{or} \quad M_3'' = 63 + 11 = 74$$

Because 74 link does not exist, the nearest link 71 is chosen. Following the same procedure the fourth-hierarchy stations are located, the selected links are 7, 16, 27, 41, 50, 60, 69 and 78 respectively. The locations of these selected sampling stations are shown in Fig. 2. In total, 16 stations with sequential priority have been identified. Here only four hierarchies are considered, however more stations could be identified by using the higher order of hierarchies.

The sampling reaches selected on the basis of number of tributaries are tabulated in Table-7:

Table-7 : Topographic location according to tributaries.

Hierarchy	Tributary Number
0	83
1	43
2	22, 63
3	12, 34, 56, 71
4	7, 16, 27, 41, 50, 60, 69, 78

6.2 Sequential Sampling Based on Pollution Loadings :

The Sharp's procedure can be successfully applied to identify the water quality stations on the basis of pollution loadings (Clarkson, 1978). The following procedure is adopted :

i) Compute the pollution load carried by various tributaries.

ii) Assign the number equal to the pollution load to the tributaries.

iii) Complete the numbering of the whole river using Sharp's procedure.

iv) After completing the numbering of the basin apply the Sharp's procedure to determine the sequential sampling stations using different hierarchies in the same way as determined on the basis of contributing tributaries in the previous section.

In Table-6, the pollution loadings have been tabulated. The BOD, NPK and Pesticides loading have been considered in this study. Using the four steps stated above 16 stations have been identified on the basis of four-hierarchies for each pollution loadings. The identified links based on each pollution loadings have been tabulated in Table-8. The networks of sequential monitoring water quality sites based on BOD, NPK and pesticides loadings have been shown in Fig. 3, 4 and 5 respectively.

One can proceed further in the same manner to determine higher level of hierarchical (lower priority) stations, as long as economic considerations permit and information expectations require doing so. To isolate a source of pollution, Sharp proposed that samples be drawn at one hierarchy and analysed to

Table-8. Selected sites on the basis of pollution loadings

Order of Hierarchy	BOD Loadings	NPK Loadings	Pesticides Loadings
Hierarchy - 0	428151	91619	233
Hierarchy - 1	224929	47523	155
Hierarchy - 2	15336, 33000	23761,69571	58,185
Hierarchy - 3	76680,186633, 27900,374297	11880,35642 58547,80595	28,94,170,208
Hierarchy - 4	38340,74398, 167563,191776, 266443,306524, 354853,394551	5940,17820 29701,41583 53035,64059, 75083,86107	14,43,76,125 163,178,197, 220

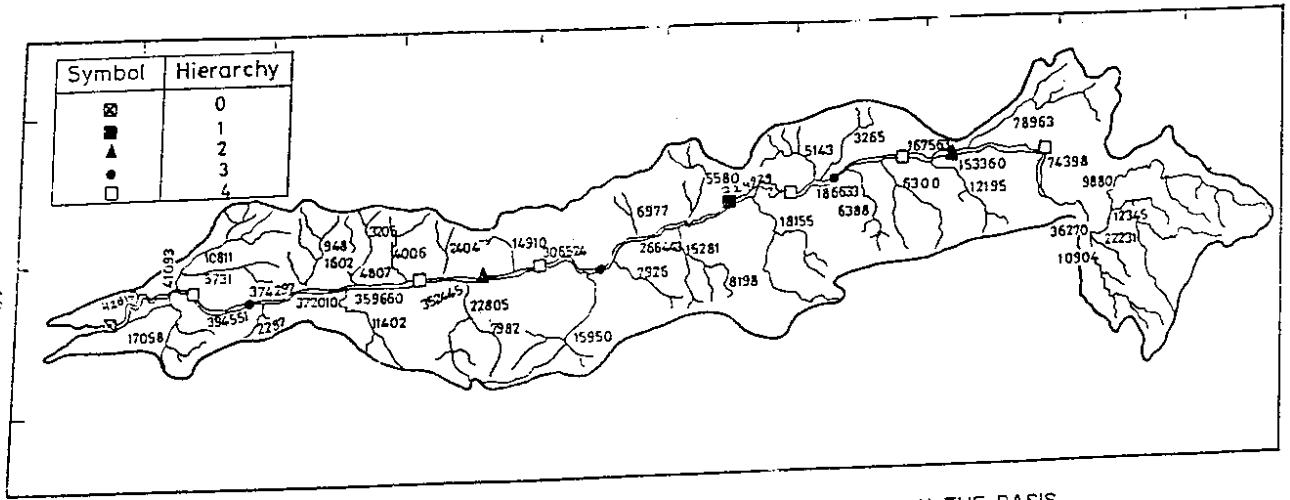

FIG. 3 NETWORK OF SEQUENTIAL MONITORING WATER QUALITY SITES ON THE BASIS OF B.O.D. LOAD (Kg/day)

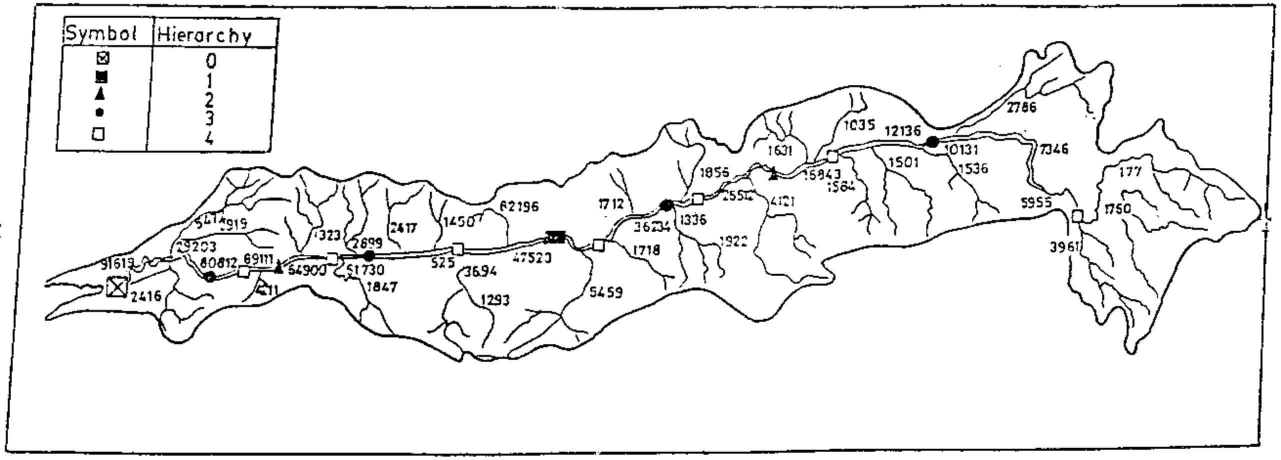

FIG. 4 OPTIMUM LOCATION OF THE SEQUENTIAL WATER SAMPLING SITES ACCORDING TO N P K-LOAD (Kg/day)

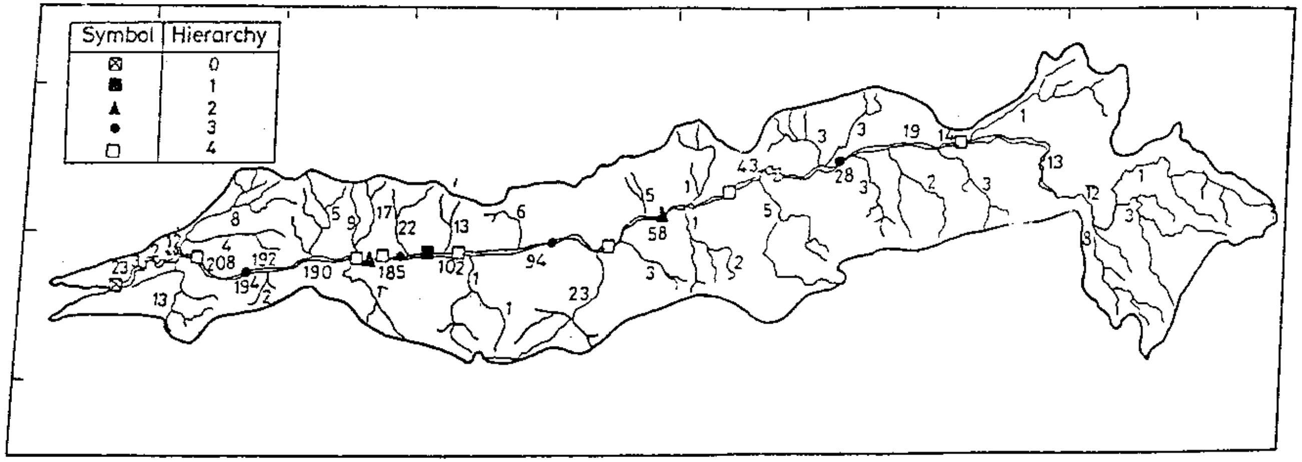

FIG. 5 NETWORK OF SEQUENTIAL MONITORING WATER QUALITY SITES ON THE BASIS OF PESTICIDE-LOAD (Kg/day)

select those portions of the river network which should be sampled at stations of the next hierarchy, and so on, until the pollutant source had been found by a process of elimination.

Assuming that the source of pollution is entring the stream through an exterior link, the modal number of samples needed to search the basin is (Sharp, 1971):

$$S_{max} = \{1 + (\log_2 M_0)\} \quad \text{---------------(5)}$$

The maximum and minimum levels of hierarchies required to search a basin for a single source of poolution are (Sharp, 1971):

$$S_{max} = 2\{1 + (\log_3 M_0)\} \quad \text{---------------(6)}$$

$$S_{min} = (\log_3 M_0) \quad \text{---------------(7)}$$

In the present case the modal number of hierarchy as given by (5) is 7. The maximum and minimum levels of hierarchies as computed from (6) and (7) are 10 and 4.

A modified Sharps procedure is proposed to designate sampling sites except that hierarchies will denote priorities for sampling rather than a sequence in which to sample. If the budget permit, one could sample simultaneously at all first and second hierarchy sites, then third hierarchy sites would be added, and so on, where sampling at additional hierarchies in effect steadily improves the resolutions of the picture obtained of the whole river network. Increasing levels of hierarchy correspond to decreasing levels of sampling priority when trying to isolate a pollutant source.

It must be emphasized that the locations of sampling stations determined above are not to be strictly applied. Engineering judgement may require that they may be moved some distance upstream or downstream in the vicinity of the computed order numbers. As pointed out earlier the method used here in specifying locations provides only guidelines instead of strict rules in pin-pointing the appropriate sampling sites.

It must also be noted that different designers may end up with different networks even if they apply the same procedure mentioned above . The reasons may be several. For example, the selection of the first exterior tributaries may significantly affect the stream orders. However this subjective aspect of method may be minimized by judging on the basis of mean minimum flow, minimum area of recharge basin or other similar quantitative criteria. Another reason may be the scale of map used, which also affects the choice of tributaries and hence location of the sampling sites.

7.0 Result and Discussions :

The sequential water quality monitoring networks based on tributaries, BOD loadings, NPK loadings and Pesticides loadings have been shown in Fig.2 to Fig.5 respectively. The comparison map of monitoring stations has been prepared to visualize the network evolved on the basis of these four criterias. It is observed from Fig.2 that the monitoring stations based on the tributaries are more or less equally spaced. While the monitoring sites based on BOD loadings, NPK loadings and Pesticides are closely located towards the downstream side of the basin. This seems to be logical because the upper basin does not have any significant pollution problem and hence monitoring sites are widely spaced. But the middle and the lower part of The Narmada basin have densely spaced monitoring sites because of higher pollution loadings with respect to BOD, NPK and Pesticides. The lower basin has the highest pollution of pesticides and NPK loadings and therefore this part of the basin requires very closely spaced monitoring sites for the purpose of monitoring and consequently formulation of control strategies for controlling the pesticides and nutrient related problems.

Each of the four approaches presented - tributary based, BOD based, NPK based and pesticides based - results in sampling networks which differ somewhat, but which share a common approach towards the selection of reaches in which to sample. Although the approach is not entirely objective - it is sometimes necessary to select from two alternative reaches, while the specific siting of a sampling transect will be the result of a subjective decision made after evaluating the characteristics of a reach - it does help the designer apportion sampling resources systematically. As presented, sampling would be done at the downstream end of a selected link or reach . In practice, however, local conditions such as accessibility could easily necessitate sampling elsewhere.

Economics is an important consideration in deciding the number of hierarchies at which sampling may take place and how sampling is to be done. The cost of continuous monitoring from permanent sites must be weighed against periodic sampling. Costs will also be reflected in the variables selected, thus measuring conductivity or dissolved oxygen with probes could be considerably less expensive than measuring BOD or iron or chlorides, all other design factors being equal.

The number of different monitoring networks that could be mapped out is limited only by the number of variables which could be selected as a basis upon which to pattern a network. If two or more variables were to be measured it might be necessary to establish more than one network, but this would be costly. Furthermore some difficulty would be encountered in trying to correlate data from a network based on say, BOD with another based on suspended solids, since the data for each would be obtained from a different array of transects. A desirable feature of a sampling program would be the ability to readily compare and correlate one variable with another. A single array from which a number of variables could be measured would make comparison possible within a common framework of time and/or location, thus in measuring several variables it would appear desirable to define a sampling network in terms of a single common factor. The outfall based network or perhaps a network based on discharge from each outfall would seem to be good candidates.

While the number of tributaries contributing to a river system will remain constant over time, the number of outfalls or the quality of discharge from outfalls will gradually change. Unfortunately, the fact that the number of tributaries remains constant does not mean that there is necessarily a relationship between tributaries and the quantity, quality and location of discharges to the river network. On the otherhand, an outfall based monitoring network having a design based on today's information may no longer be correct in a few years. However this should not be considered critical. Data from a particular transect should not be considered indicative of the whole basin and because a transect is properly used to make inference on a limited region , it would be preferable to maintain the station at a fixed point over a long period of time rather than adjust it frequently to reflect changes in outfalls or discharge patterns, for if the transect is held fixed over a long period of time, a basis of comparison is assured for all the data collected at that station.

These considerations notwithstanding, it is interesting to note in comparing Fig. 2, 3, 4 and 5 that first hierarchy stations in each of the three illustrations fall at virtually the same point, and that the same is roughly true for the second hierarchy station on the lower half of the river basin. A comparative map (Fig. 6) of water quality monitoring stations on the basis of tributaries, BOD, NPK and pesticides is prepared which shows that the degree of specificity and resolution is greater for the NPK, pesticides and BOD based monitoring networks than for the tributary network, because links are greater in number and shorter in length for both BOD and pollution loading networks. However, second-hierarchy stations fall in the same general area for each of the four approaches. With a predominance of population and industry situated on the lower half of basin, such an overlap or similarity of networks might lend itself nicely to comparative analysis even if distinct network do exist. Furthermore, if it should be that sampling stations are specific locations at which samples are taken periodically but are not the locations of permanent sampling installations, cost might not be so great a factor, in which case it would be feasible to maintain several networks which are mutually comparable.

Unlike the arbitrary but common practice of sampling from sites such as bridges because they are readily accessible even though they have no necessary relationship to the data collected , the modified Sharp's procedure results in selection of sites which are not weighted to reflect density of population or industry. Thus, the stream based network is distributed fairly evenly throughout the river basin whereas stations of NPK and pesticides and BOD based networks exist predominantly in the lower half where most industry and the larger towns and cities are found.

The general method which has been presented may be used to designate sites at which to sample for water quality in a river basin. Hierarchy numbers represent the sequence with which levels of funding would limit or augment a sampling program. First-hierarchy sampling stations would be established initially, then second hierarchy stations and so on, as funding permitted or the need for additional data required. As each additional hierarchy is established, the percentage of areal coverage in the case of tributaries, or its analog in the case of outfalls or BOD is

Basis	Symbol	Hierarchy	Symbol
Tributary	1	0	⊠
BOD Load	2	1	▣
N P K Load	3	2	▲
Pesticide load	4	3	•
		4	□

FIG. 6 COMPARATIVE MAP OF WATER QUALITY MONITORING NETWORK ON THE BASIS OF TRIBUTARY, BOD, N-P-K AND PESTICIDE LOADING.

increased. For the applications based upon outfalls or BOD loading, the resulting centroids and subcentroids represent centers of mass of pollutant loading rather than centers of basin area as in the original Sharp's procedure.

7.1 Needs for improving the existing Network :

Fig.7 shows the monitoring sites on the Narmada river in MP under GEMS/MINARS Natural Water Package Programme. It is observed that the present monitoring sites are located nearer to the cities both on u/s and d/s sides of the river. This type of monitoring plan is good to monitoring and check out the pollution point source only such as domestic and industrial sources. But it is insignificant to monitor the pollution coming from the non-point sources such as agricultural fertilization, animal feedlots and other sources. Further, the present monitoring network seems to be sufficient for the u/s portion but needs improvements in the d/S portion as the pollution loading is increasing towards the downstream side which needs an extensive plan of monitoring.

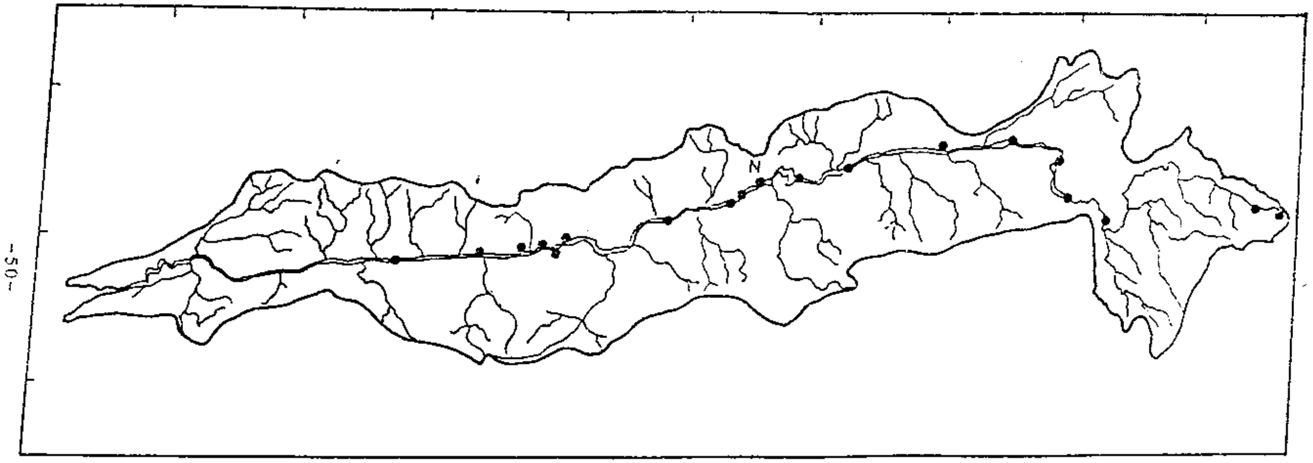

FIG. 7 MONITORING SITES OF GEMS/MINARS IN NARMADA BASIN BEING USED PRESENTLY

8.0 Conclusions :

The sequential water sampling sites to be used in the search for a pollution source have been identified for the Narmada basin. Four different criterias e.g. tributaries, BOD, NPK and Pesticides were used to locate the sampling locations. Four hierarchies have been used in the study. However, higher level of hierarchical stations can be identified subjected to the economic considerations. It was found that for the detection of single pollution source, one had to go up to the seventh level of hierarchies.

Each of the four networks presented namely tributary based, BOD loading, NPK loading and pesticides loading based differs somewhat but it share a common approach towards the selection of reaches in which to sample. It must be emphasized that locations of sampling stations determined above are not to be strictly applied. Therefore, an engineering judgement is required to locate a monitoring sites which satisfy most of the requirements and minimize the financial requirements. In this procedure, the proposed monitoring networks may be used as guidelines in pinpointing the appropriate sampling sites.

Further, it is observed that the present monitoring network is self-sufficient as far as the middle and upper basin is concerned. But it certainly needs improvement in the downstream portion of the basin particularly for controlling the pesticides, nutrient related problems in the lower basin.

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