Chapter VII

CHAPTER VII

HYDROLOGICAL ASPECTS IN OPERATION AND MAINTENANCE

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RESERVOIR OPERATION

RESERVOIR WATER BALANCE

RIVER FLOW FORECASTING

WATER QUALITY MODELLING & MONITORING

ENVIRONMENTAL IMPACT ASSESSMENT

RESERVOIR OPERATION

THE NEED FOR RESERVOIRS

Reservoirs are one of the most important component of a water resources development project. A reservoir is created by constructing a dam across a stream. The principal function of a reservoir is regulation of natural streamflow by storing surplus water in the high flow season and releasing the stored water in the dry season to supplement the natural stream flow. The water stored in a reservoir may be diverted to far away places by means of pipes or canals resulting in spatial changes or it may be stored in the reservoir and released later for beneficial uses giving rise to temporal changes. In short, the purpose of a reservoir is to change the temporal and spatial availability of water according to the demands.

Depending upon the magnitude of natural inflows and demands at a particular time, water is either stored in the reservoir or is supplied from the storage. As a result of storing water, a reservoir provides head of water which can be used for generation of electric power. The reservoir also provides empty space for storage of water thereby moderating the inflow peaks. A reservoir also provides pool for navigation to negotiate rapids, habitat for aqua life and facilities for recreation and sports. It enhances scenic beauty, promotes afforestation and wild life.

Depending upon the number of purposes which a reservoir is designed to serve, a reservoir may be classified either as a single purpose reservoir or as a multipurpose reservoir. A single purpose reservoir serves only one purpose. This purposes may be either a conservation purpose, e.g., water supply for irrigation, navigation, or municipal and industrial needs, generation of hydroelectric power, or flood control. A multipurpose reservoir is developed to satisfy more than one of the above purposes.

THE RESERVOIR OPERATION PROBLEM

Once a reservoir comes into being, the benefits that could be reaped depend, to a large extent, upon how well it is managed. The efficient use of water resources requires not only judicious design but also proper management after construction. Reservoir operation forms a very important part of planning and management of water resources system. Once a reservoir has been developed, detailed guidelines have to be given to the operator which enable him to take decisions about storing or releasing water.

The conservation demands are best served when the reservoir is as much full as possible at the end of the filling period. The flood control purpose, on the other hand, requires empty storage space so that the incoming floods can be absorbed and moderated to permissible limits. The conflict between the two purposes in terms of storage space requirements is resolved through proper operation of reservoirs.

A reservoir operation policy should specify the releases from storage at any time as a function of the current state of the reservoir, the magnitude of current and near-term demands, and the likely inflows and must be in conformity with the stated objectives. The development of operation policy of a multipurpose reservoir, particularly when the conservation purposes are combined with flood control, is a complex task because of their conflicting nature. A full reservoir is needed to maximize returns from conservation uses while empty reservoir gives maximum benefits from flood control. The operation policy should optimally resolve the conflicts among the various purposes.

CHARACTERISTICS AND REQUIREMENTS OF WATER USES

The complexity of the problem of reservoir operation depends upon the extent to which the various purposes which a reservoir is supposed to serve are compatible. If the purposes are relatively more compatible, the coordination is easier. The requirements of different purposes are explained below :

Irrigation

The irrigation requirements are seasonal in nature and the variation largely depends upon the cropping pattern in the command area. The irrigation demands are consumptive in nature and only a small fraction of the water supplied is available to the system as return flow. These requirements have direct correlation with the rainfall in the command area. The safety against drought depends upon the storage available in the reservoir and hence it is desirable to maintain as much reserve water in storage as possible consistent with the current demands.

Hydroelectric Power

The hydroelectric power demands usually vary seasonally and to a lesser extent daily and hourly too. The degree of fluctuation depends upon the type of loads being served, viz., industrial, municipal and agricultural. Hydroelectric power demand comes under the non-consumptive use of water.

Municipal and Industrial Water Supply

Generally, the water requirements for municipal and industrial purposes are quite constant throughout the year, more so when compared with the requirements for irrigation and hydroelectric power. The water requirements increase from year to year due to growth and expansion. The seasonal demand peak is observed in summer. The supply system for such purposes is designed for very high level of reliability.

Flood Control

Flood control reservoirs are designed to moderate the flood flows that enter the reservoirs. The flood moderation is achieved by storing a part of inflows in the reservoir and making releases so that the damages in the downstream areas are minimum. The degree of moderation or flood attenuation depends upon the empty storage space available in the reservoir when the flood impinges it. As far as possible, the releases from the storage are kept less than the safe capacity of downstream channel.

Navigation

Many times storage reservoirs are designed to make a stretch of river downstream of the reservoir navigable by maintaining sufficient flow depth in the channel. The water requirements for navigation show a marked seasonal variation. The demand during any period also depends upon the type and volume of traffic in the navigable waterways.

Recreation

The benefits from this aspect of reservoir are derived when the reservoir is used for swimming, boating, fishing and other water sports and picnic. Usually the recreation benefits are incidental to other uses of the reservoir and rarely a reservoir is operated for recreation purposes. Large and rapid fluctuations in water level of a reservoir are deterrent to recreation.

CONFLICTS IN RESERVOIR OPERATION

While operating a reservoir which serves more than one purpose, a number of conflicts arise among demands of various purposes. The conflicts which arise in multipurpose reservoir operation may be classified as:

Conflicts in Space

These type of conflicts occur when a reservoir (of limited storage) is required to satisfy divergent purposes, for example, water conservation and flood control. If the geological and topographic features of the dam site and the funds available for the project permit, a dam of sufficient height can be built and storage space can be clearly allocated for each purpose. In case of reservoirs with seasonal storage, flood control space can be kept empty to moderate the incoming floods and the conservation pool can be operated after the filling season to meet the conservation demands. However, this essentially amounts to saying that a multipurpose reservoir is a combination of several single purpose reservoirs.

Conflicts in Time

The temporal conflicts in reservoir operation occur when the use pattern of water varies with the purpose. The conflicts arise because release for one purpose does not agree with the other purpose. For example, irrigation demands may show one pattern of variation depending upon the crops, season and rainfall while the hydroelectric power demands may have a different variation. In such situations, the aim of deriving an operating policy is to optimally resolve these conflicts.

Conflicts in Discharge

The conflicts in daily discharge are experienced for a reservoir which serves for more than one purposes. In case of a reservoir serving for consumptive use and hydroelectric power generation, the releases for the two purposes may vary considerably in the span of one day. Many times a small conservation pool is created on the river downstream of the powerhouse which is used to damp the oscillations in the powerhouse releases.

CONVENTIONAL TECHNIQUES OF RESERVOIR OPERATION

A reservoir is operated according to a set of rules or guidelines for storing and releasing water depending upon the purposes it is required to serve. The decisions are made to make releases in different time periods in accordance with the water in storage and demands.

For reservoirs which are designed for multiannual storage, the operation policy is based on long term targets. The estimates of water availability are made using long term data. The demand for conservation uses like irrigation, water supply, navigation and hydroelectric power are worked out by projecting the demand figures. If hydroelectric power generation is not one of the purposes of the reservoir, water is allocated among various consumptive uses. The extent of water releases for variety of uses which can be served from storage in the reservoir on long term basis are determined and the reservoir is operated accordingly. In the period of drought, based on prespecified priorities, the supply for some uses is curtailed keeping in view bare minimum demands of each purpose. Consideration is given to the maintenance of essential services even if it is at the cost of agriculture and industrial production. If generation of power is one of the purposes of the reservoir, then releases for consumptive uses are routed through the power house to generate the required energy.

The operating policy of reservoirs designed and operated for seasonal storage is based on yearly operation. Reservoir operation study is carried out for long term record taking into account the demand estimates for various conservation uses. Policy decisions are arrived at introducing the concepts of reliability. In a country like India, where most of the rainfall is concentrated in monsoon months, water demands can generally be met during the monsoon period. For meeting water demands during non-monsoon months, a fair idea of the water availability is required and the reservoir operation for the year is planned on the basis of earlier decided policy. If necessary, allocation for some purposes can be curtailed, based on priority. In multipurpose storage reservoirs located in the regions where floods can be experienced at any time of the year and flood control is one of the main purposes, permanent allocation of the space exclusively for flood control at the top of conservation pool becomes necessary. Flood control space is always kept reserved although the space may vary according to the magnitude of floods likely to occur. The flood storage space allocation at different times of the year is so determined that incoming floods would be absorbed or mitigated to a large degree and that even when a maximum probable flood is likely to occur, its peak will be substantially reduced and flood damage on the downstream would not exceed permissible limits. In reservoirs in regions where floods are experienced only in a particular season or period of the year, seasonal allocation of space is made for flood control during different periods of flood season depending upon the magnitude of floods likely to occur in given period and the space is thereafter utilized for storing inflows for conservation uses.

Standard Linear Operating Policy

The simplest of the reservoir operation policies is the standard linear operating policy (SLOP). According to this policy, if the amount of water available in storage is less than the target release, whatever quantity is available is released. If availability is more than target, then a release equal to the target is made as long as storage space is available to store excess water and thereafter, all the water in excess of maximum storage capacity is released. This policy is graphically represented in Figure 1.1.

The policy stated above is a one-time operation policy without relation to the release of water at any other time. This type of time isolated releases of water is neither beneficial nor desirable. The water beyond the target output in any period has very little economic value. This policy is not used in day-to-day operation due to its rigidity and above drawbacks. It is however, extensively used in planning studies.

Rule Curves

The reservoirs are frequently operated using the rule curves. A rule curve or rule level specifies the storage or empty space to be maintained in a reservoir during different times of the year. Here the implicit assumption is that a reservoir can best satisfy its purposes if the storage levels or empty space specified by the rule curve are maintained in the reservoir at different times. The rule curve as such does not give the amount of water to be released from the reservoir. This amount will depend upon the inflows to the reservoir, or sometimes it is specified in addition to rule curves.

The rule curves are generally derived by operation studies using historic or generated flows. Many times due to various conditions like low inflows, minimum requirements for demands etc., it is not possible to stick to the rule with respect to storage levels. It is possible to return to the rule levels in several ways. One can be to return to the rule curve by

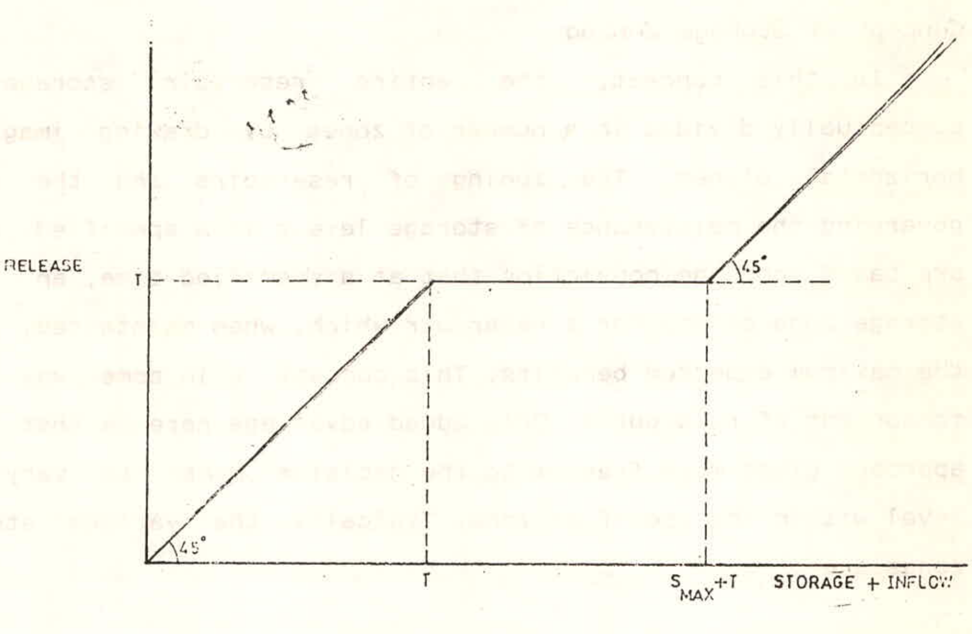


Fig.1.1- CONVENTIONAL RESERVOIR OPERATION POLICY

curtailing the release beyond the minimum required if the deviation is negative, or releasing an amount equal to safe carrying capacity if the deviation is positive.

The rule curves implicitly reflect the established trade-off among various project objectives in the long run. For short term operations they serve only as a guide. The operation of a reservoir by strictly following rule curves becomes quite rigid. Many times, in order to provide flexibility in operation, different rule curves are followed in different circumstances.

Concept of Storage Zoning

In this concept, the entire reservoir storage is conceptually divided in a number of zones by drawing imaginary horizontal planes. The zoning of reservoirs and the rules governing the maintenance of storage levels in a specified range are based upon the conviction that at a specified time, an ideal storage zone exists for a reservoir which, when maintained, gives the maximum expected benefits. This concept is in some way akin to concept of rule curve. Only added advantage here is that this approach gives more freedom to the decision maker to vary the level within the specified zone. Typically the various storage zones are :

(i) Dead storage zone: Also called inactive zone, the space in this zone is normally meant to absorb some of the sediment entering the reservoir or to provide minimum head for hydropower plants. The water in this zone may be utilized only under extreme dry conditions. This is the lowest zone of a reservoir.

(ii) Buffer zone: This is the storage space on the top of dead storage zone and the reservoir level is brought down to this zone under extreme drought situations. When the reservoir is in this zone, the release from the reservoirs caters only to essential needs.

(iii) Conservation zone: This is the zone in which the water is stored to satisfy the demands for various conservation purposes like hydropower, irrigation and water supply etc. This zone provides the bulk of the storage space in reservoirs designed for conservation purposes.

(iv) Flood control zone: This is the storage space exclusively earmarked for absorbing floods during high flood periods. This zone is located on top of conservation zone. The releases are increased as necessary when the water stored in the reservoir falls in this zone.

(v) Spill zone: This storage space above the flood control zone corresponds to the flood rise during extreme floods and spilling. This space is occupied mostly during high flows and the releases are at or near maximum.

The graphical representation of the various zones is shown in fig. 1.2.

The normal operation policy is to release as much as possible when the reservoir is in the spill zone, to release as much as possible without causing flood damages downstream when the reservoir content is in flood control zone, and to bring the reservoir to the top of the conservation zone at the earliest possible time. The release from the conservation zone is governed by the requirements of water for various purposes intended to be met by the stored water and the day to day releases may be adjusted based on the inflow anticipated and the future requirements up to the end of the operating horizons. When the

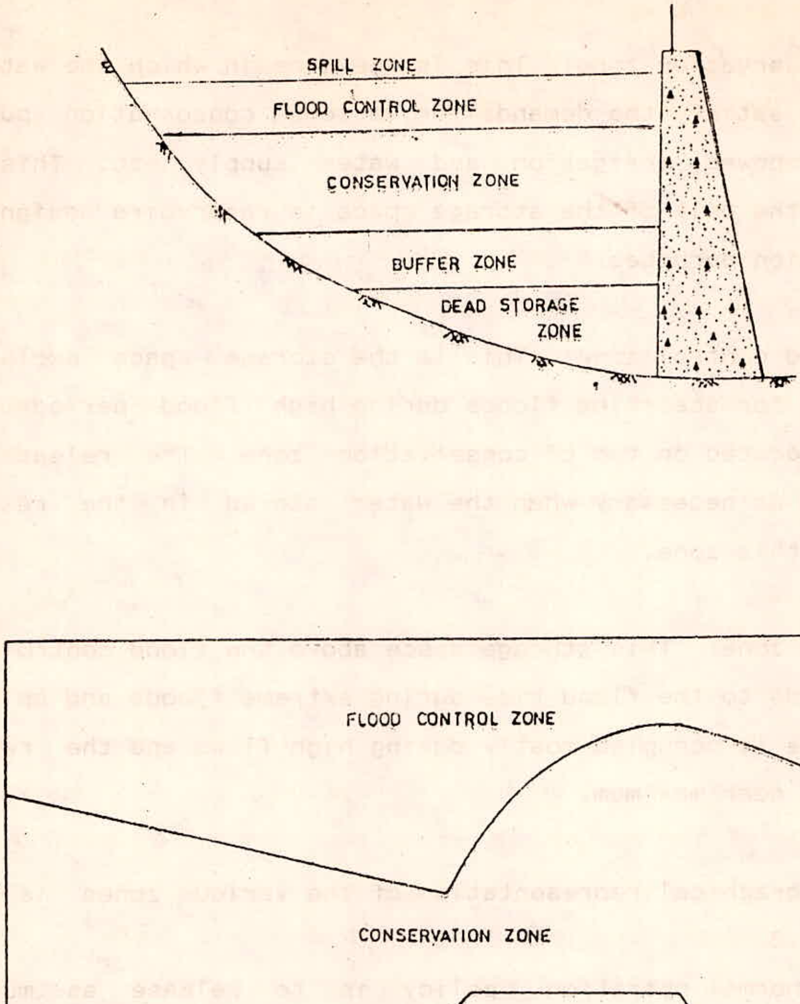


Fig.1.2- SCHEMATIC REPRESENTATION OF VARIOUS RESERVOIR ZONES

amount of water is anticipated to be short compared to the demand, releases may be curtailed. The limits of various zones may vary with time.

SYSTEM ENGINEERING TECHNIQUES

System engineering is concerned with decision making for those systems on which some controls can be applied to best obtain the given objective subject to various social, political, financial and other constraints. A number of system engineering techniques are available for solving various problems associated with reserveir operation. Among them, two techniques which are most commonly used are simulation and optimization.

Simulation

Simulation is the process of designing a computerized model of a system and conducting experiments with it for understanding the behaviour of the system and for evaluating various strategies for its operation. Essence of simulation is to reproduce the behaviour of the system. It allows for controlled experimentation on the problem without causing any disturbance to the real system. However, simulation analysis does not yield an immediate optimal answer and require a number of iterations to arrive at the optimum solution.

Optimization Techniques

Optimization is the science of choosing the best amongst a number of possible alternatives. In many engineering problems, a situation arises in which there are many ways of doing a particular thing. For example, a number of alternative designs may be available to serve the required need, a number of management decisions may be available to increase the production and a number of release decisions may be available to cater for irrigation and hydroelectric power. Naturally, the result attained in each case will be different and hence it is required to evaluate each alternative and then choose the best from the point of view of interest, say economical, physical or convenience etc.

The optimum seeking methods are also known as mathematical programming techniques. Depending upon the nature of the objective function and constraints, the available optimization techniques can be classified in several ways, viz., linear or non linear optimization, deterministic or stochastic optimization, constrained or unconstrained optimization etc.

The brief discussion of methods is being made under the following heads:

(a) Linear programming (LP),
(b) Nonlinear programming (NLP), and
(c) Dynamic programming (DP).

LINEAR PROGRAMMING

The optimization problems in which the objective functions and constraints are linear function of decision variables along with the condition that the decision variables are positive are termed as Linear Programming (LP) problems. Although the objective function and decision variables are not linear in nature in many water resources problems, they can be approximated by linear functions and LP can be used to obtain the solution. A very efficient solution technique for the LP problems was developed by Dantzig which is known as the Simplex Method.

Nowadays very efficient computer packages are available for solution of LP problems which make the use of this technique very attractive. Post optimality analysis in an important part of any optimization problem. This is concerned with finding out as to how the optimal solution changes with change in the various coefficients of a problem. Other topics of interest in linear programming include the transportation problem and the assignment problem. Reference is made to Rao(1979) and Taha(1976) for further reading.

NONLINEAR PROGRAMMING

As mentioned earlier, the pre-condition of application of LP is that the objective function and constraints must be linear. However, in many engineering problems this may not be the condition. Further, the possible remedy of linearising these functions may lead to unwanted distortions in the objective functions and constraints. In such cases, the technique of NLP is used to solve the problem.

A number of optimization methods for nonlinear optimization problems make use of gradient of the function. The gradient of a function is a vector containing partial derivatives of the function with respect to each of the variables. The property of the gradient which is most useful from optimization point of view is that if we move along the direction of the gradient, the function value changes at the fastest rate. If we move on the steepest slope, the convergence to the optimum is quickest.

Mainly due to the non availability of software, the use of nonlinear programming in solving the problems of water resources system is somewhat limited.

DYNAMIC PROGRAMMING

Dynamic programming is defined as an enumerative technique which can be used to obtain optimal solution to a variety of problems. Dynamic programming was developed by Richard Bellman. Its entire theory is based upon Bellman's principle of optimality. In the dynamic programming formulation, the dynamic behavior of the system is expressed in terms of three variables; (i) state variables which describe the system, (ii) control variables which represent the decision or control applied and influence the process by effecting the state variables in some prescribed fashion, and (iii) the stage variables which determine the order in which events occur in the system. Generally, the stage variable is taken to be time. The system is described by a set of equations called system equations which describe how the stage variables at the given stage are related to those at the next stage, on application of controls.

The DP technique has also been applied to non-sequential problems. Some of its advantages are:

(i) It can find the optimal solution even when the feasible region is not convex.

(ii) The solution can be found in cases where the variables are not continuous. Several problems in system design can not be realistically and effectively formulated using the concept of continuous variables.

(iii) It also provides solution to a number of problems where classic methods of calculus fail.

REFERENCES

1. Hall,W.A., and J.A. Dracup, Water Resources Systems Engineering, Tata McGraw-Hill Publishing Company, New Delhi, 1979.
2. Loucks, D.P., J.R. Stedinger, and D.A. Haith, Water Resources Systems Planning and Analysis, Prentice Hall Inc., New Jersey, 1981.
3. Rao, S.S., Optimization, Theory and Practice, Wiley Eastern, 1979.
4. Taha, H., Operations Research, an Introduction, Macmillan Publishing Company, 1976.
5. Yeh, William W-G., "Reservoir management & operation models : A state of the art review", Water Resources Research, 21(12), 1797-1818, 1985.

RESERVOIR WATER BALANCE

INTRODUCTION

The reservoirs are constructed to reduce the variability in the downstream. The aim is to change the natural availability in a beneficial way and provide assured water supply, mitigate floods, and generate hydroelectric energy. These are the most common purposes for which reservoirs are constructed in our country although benefits are also derived from other incidental uses. It has been estimated that water bodies, excluding oceans, occupy 1.4% of world's total area. The total full volume of 10000 major reservoirs of the world is about 5000 Cubic km which is equivalent to about 11% of total annual runoff from the surface of the land. The total water surface area of reservoirs is estimated to be about 600,00 sq km. These figures give an idea as to how big the reservoirs are. The use of reservoirs in river regulation can not be ignored.

Importance of Water Balance of Reservoir

The term 'water balance' in the context used here signifies quantitative assessment of various components of water balance equation of a reservoir. While studying water balance, it is indispensable to adhere to the law of conservation of mass. However, due to a large number of variables involved which defy an exact quantification, the water balance of a reservoir cannot be watertight, errors occur while closing the water balance equation and these are to be appropriately considered.

Water besides being essential for sustaining of life, is an important input resource in a number of economic activities. Due to its scarcity in many regions of the world and increasing depletion in other regions because of growing population, greater emphasis is being placed on better management of water resources. To take better reservoir operating decisions, it is required to have a complete quantitative understanding of the water cycle of a reservoir. Predictions of water balance components are also very helpful in design of reservoirs. A knowledge of these components can give a significant contribution to the study of extreme events and climate variability. These studies are also useful in estimation of components of water balance like seepage etc. whose direct determination is quite difficult.

COMPONENTS OF WATER BALANCE EQUATION FOR A RESERVOIR

The water balance equation for a reservoir is nothing but the mass balance or continuity equation. This equation states that the sum of inflow and outflow components and change in storage (with appropriate signs) must be zero over a given time interval. In the simplest form, the equation can be expressed as:

$$I_s + I_g + P - E - Q - L - \Delta S \pm \delta = 0 \qquad (1)$$

where,

I_s = Surface water inflow into the reservoir,

I_g = Groundwater inflow into the reservoir,

P = Precipitation on the surface of reservoir,

Q = Release from the reservoir,

E = Evaporation from the reservoir.

L = Storage losses including seepage etc.,

ΔS = Change in reservoir storage during the period of computation, and

δ = Error term.

The water enters in the reservoir through surface inflow and direct precipitation; the water that leaves reservoir comprises of releases through outlets and spillways, evaporation and losses due to seepage. The reservoir storage increases if the inflow exceeds outflow and decreases if the outflow exceeds inflow. All the components of water balance equation should be independently estimated. The term δ in the above equation (1) represents the net effect of errors involved in the estimation of different components. In practice it is quite likely that errors will be present while measuring or computing various terms involved in the water balance computation and the left hand side may not sum to zero. Thus a large value of δ represents significant error in estimating different variables involved in equation (1). However, a small value of δ does not indicate that the errors are small. The errors may be opposite in sign and thus may balance themselves. The components of water balance of a reservoir are diagramatically shown in figure 1.

The water balance equation (1) may be applied for any time interval. Mean water balance is a term specifically used for computations which are spread over an annual cycle e.g., a calendar year or a water year. Sometimes this term is also used for seasonal water balances. The computations of mean water balance are simplest in nature. However, with the reduction of computational period, a more detailed accounting procedure is required. The additional factors which are to be included in the computations include bank storage during reservoir filling, water loss due to water and ice left on the banks when the reservoir is drawn down and return of this water to reservoir later on. The following equation was proposed to Vikulina (1970) for water balance computations for a short time interval (a month)

$$Q_s + P - Q - E \pm Q_i = S \qquad (2)$$

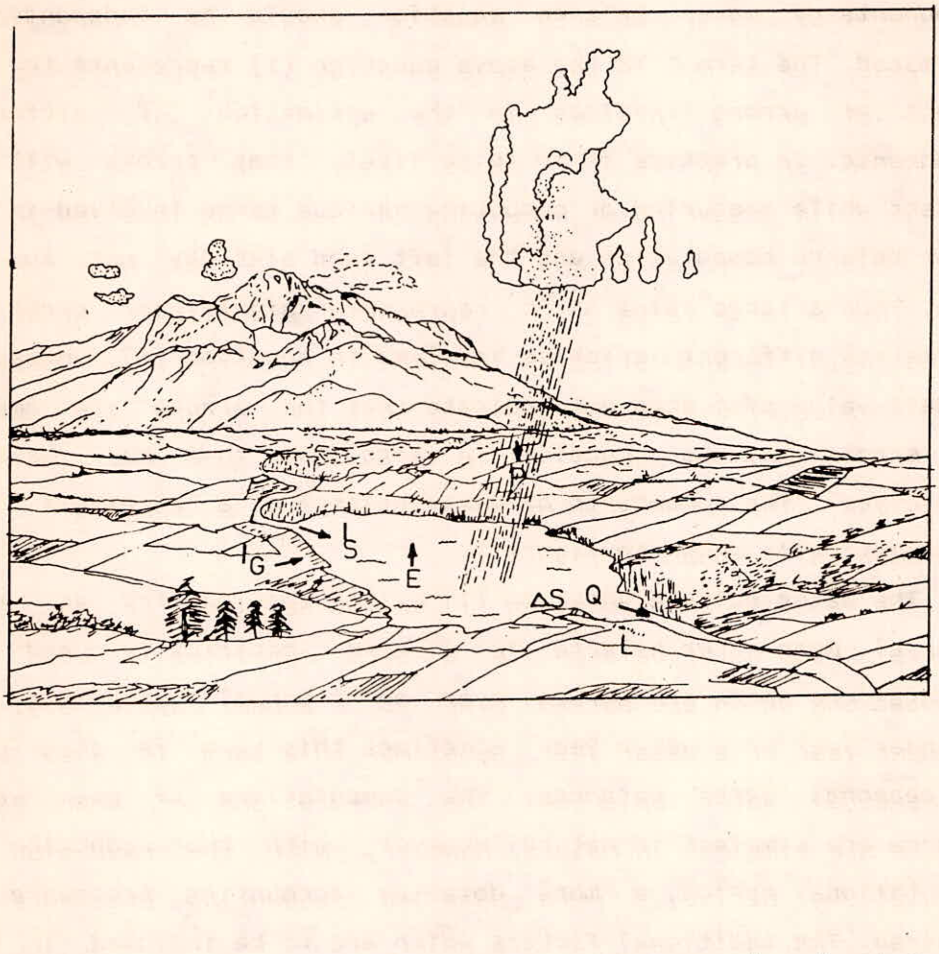


FIG.1 Diagramatic representation of components of water balance of a reservoir (adapted from Ferguson & Znamensky)

where,

Q_s = temporary water losses by saturation of shores of the reservoir,

Q_i = temporary water losses by the ice left on the shores after the fall of level of the reservoir.

The accuracy of water balance components as well as the duration of the design interval are stipulated by the accuracy of determination of balance components. The most important components are the surface inflow and change in storage. Vikulina (1979) proposed the following equation to determine relative error B_e (%) of water storage changes compared to the inflows :

$$B_e = \frac{10^4 A_w \delta_h}{86400 I_s T}$$

A_w = water surface area of the reservoir in km^2,

δ_h = error of mean level estimation (m),

I_s = discharge into the reservoir,

T = time interval or duration of balance period(in days).

This equation can be used to determine the length of balance period such that B_e is less than ± 5%.

Estimation of Surface Inflow

Surface inflow is the most important component of income part of the water balance equation for reservoirs. It can be determined by direct measurement, can be computed using direct measurement of related variables or can be estimated indirectly. The total surface water inflow in the reservoir can be subdivided into two components : Contributions of the main rivers debauching in the reservoir and the runoff from the surrounding area which directly enters in the reservoir.

The site at which streamflow measurements are carried out is called a gauging site. The location of the gauging site may be little away from the reservoir to avoid the back water effect and in such cases, the contribution of the area lying between the gauging site and the rim of the reservoir has to be considered to arrive at the correct figure. Most commonly the variables measured at the gauging site are river stage and discharge. If only river state is measured at the gauging site, discharge can be estimated using the rating curve at the site. A large number of methods are available to determine streamflow at a particular site. These methods include the velocity area method, slope area method moving boat method, dilution methods and ultrasonic method. These methods are described in great detail by Herschy (1978). Selection of a particular method largely depends upon the site and flow conditions, equipment available and accuracy requirements.

In case no measured data are available for the drainage basin surrounding the reservoir, techniques discussed below may be used to estimate inflow to the reservoir. These are described in greater detail in Ferguson and Znamensky (1981).

Estimation of Precipitation

It has been estimated that precipitation falling directly over the reservoir surface forms approximately 17 % of total water input to reservoirs in Asia, Unesco (1974). For a particular reservoir, the contribution of this component increases with increase in surface area of the reservoir. Precipitation is the most important meteorological parameter and apart from the water balance computations, it is extensively used in tasks such as rainfall runoff modelling, flood forecasting and reservoir operation.

The measurement of precipitation is carried out using the precipitation gauges which give the point values of precipitation.

The precipitation, however, is not uniform over a particular area. Therefore some procedure is required to estimate total amount of precipitation falling over the given area using the point measurements available at a number of gauges scattered over the area. A large variety of instruments and techniques have been developed for gathering information on various phases of precipitation. On the instrument side, the most important ones are those measuring the quantity and intensity of precipitation although devices for measuring the raindrop size distribution and for the time of beginning and ending precipitation are also available, Linsley et al (1975). The measurements of precipitation are expressed in terms of vertical depth of water which would accumulate on a level surface if the precipitation remained where it fell. The gauges which are commonly used to measure rainfall include weighing type, Siphon type and Tipping bucket raingauge. Of late, radar is also being increasingly used for estimation of precipitation.

The precipitation gauges are subject to various errors.. The individual error components may be small in magnitude but the cumulative effect is to yield a low value of observation. Among the errors, the most serious is the deficiency of measurements due to winds; other components caused by evaporation adhesion etc. are small. The deficiency increases with the reduction in raindrop size and thus it is greater for light rain. A number of shields have been developed and various agencies have recommended the use of wind shields particularly if the incidence of light rain or drizzle is high or a portion of catch is snow. The deficiency of catch varies from place to place and hence attention must be paid while applying corrections. The site for establishing a gauge should also be carefully selected. Preferably, the site should have level ground in its vicinity with bushes and trees serving as wind break. These however should not be too close to the gauge to affect the catch. The obstacles which serve as wind break should subtend an angle of at least 20° to 30° from the gauge orifice.

Evaporation

The term evaporation is defined as the net rate of transfer of vapor to atmosphere. The degree of evaporation depends upon the nature of the evaporating surface and meteorological factors. The present discussion is limited to evaporation from free water surface.

The evaporation can be thought of as an energy exchange process. The most important factor in the process is radiation followed by wind speed and vapour pressure of the air overlying the surface. The amount of evaporation also varies with latitude, season, time of day and condition of sky. It is difficult to categorically express the relative effect of the controlling meteorological factors, if radiation exchange and all other meteorological elements are constant over a shallow lake for a considerable time, the temperature of water and evaporation would become constant. If the wind speed is then suddenly doubled then the rate of evaporation would also be double for some time. However, this rate would start decreasing as the increased rate than could be replaced by radiation and conduction and consequently water would achieve a lower equilibrium temperature.

The quality of water in a reservoir also affects evaporation although the change may be marginal. This reduction takes place because the dissolved solids reduce the vapour pressure of the evaporation, the temperature of water rises and this partially offsets the effect of reduction in vapour pressure. Moreover, any foreign material which affects the reflectivity property of water surface tends to affect evaporation.

ESTIMATION OF EVAPORATION

The instrument Pan evaporimeter is most commonly used to estimate evaporation from water bodies. The pan is a shallow (and mostly) circular vessel exposed to atmosphere..The pans can be installed in three ways: on the land surface, sunked in ground and floating on water surface. The pans installed on or above the ground surface experience little higher evaporation since extra heat is absorbed by the side walls. This can be minimized by suitably isolating the pan. However, this effect must be suitably considered while estimating the evaporation from the reservoir using the pan evaporation measurements. The main advantages of surface pan are economy and ease of installation maintenance and operation.

By burying the pan, the objectionable effects due to radiation on the side walls are eliminated. But on the other hand these pans are difficult to install, maintain, repair and observe. It is also difficult to detect the leakage which may take place from the pan. The heat exchange between pan and soil is appreciable. The height of vegetation adjacent to pan must also be limited.

The estimation of evaporation from a reservoir can be most nearly approximated by a pan floating on lake surface. However, the installation and maintenance expenses are quite large. Observation of data is very difficult and many times, splashing takes place which renders the records unreliable. Due to these reasons, these plans are not very common in use.

Among the various types of pans in use throughout the world, the most widely used is the US Weather Bureau Class A Pan. This pan is made of unpainted galvanized iron. Its shape is circular with diameter 122 cm. and depth 25.4 cm. It is recommended that this pan be mounted on a wooden frame so that air may circulate beneath it. The pan must be filled to a depth of 20 cm and it should be refilled when the depth of water falls to 18 cm. The water level can be measured using a hook gauge. The evaporation is computed as the difference between the water levels measured after accounting for precipitation.

The estimate of evaporation can be obtained by multiplying the pan evaporation by a coefficient called pan coefficient. The average value of pan coefficient for US Weather Bureau class A pan is 0.70. The value of this coefficient can vary regionally, it is low in arid regions and higher in humid. Many times, it is necessary to cover the pan with a screen to prevent loss of water due to drinking by animals and birds. The use of screen changes the pan coefficient. The change can be as much as 14%.

ENERGY BUDGET METHOD

In the energy budget method determination of evaporation from the reservoir, the energy input and output from the reservoir is accounted and the residual is assumed to have been consumed for evaporation. Along with energy balance, a rough water balance is also required since water storage and inflow/outflow represent energy values.

The energy budget for a reservoir may be written as

$$R_n - R_h - R_r - R_v = 0 \qquad (4)$$

where,

R_n = Net radiation absorbed by the reservoir,

R_h = sensible heat transfer to atmosphere through conduction

R_e = energy used for evaporation

R_r = energy stored in the reservoir

R_v = net energy content of in flowing and out flowing water

The units used in the above equation are calories per square centimeter. The term sensible heat transfer can not be directly observed or computed. Let H_q represent latent heat of vaporization and R the ratio of heat loss by conduction to heat loss by evaporation or Bowen ratio. Thus the above equation can be written as :

$$E = (R_n + R_v - R_r) / \rho H_v (1 + R) \qquad (5)$$

where

E = evaporation in centimeters,

ρ = density of water.

The Bowen ratio can be computed by the following equation

$$R = 0.61 (T_o - T_a) p / 1000.0 (e_o - e_a) \qquad (6)$$

Where

p = atmospheric pressure,

T_o = water surface temperature,

T_a = temperature of air,

e_o = saturation vapour pressure corresponding to T_o,

e_a = vapour pressure of air.

The above equation is valid for normal atmospheric conditions. The limiting values of the constant (0.61) in the above equation are 0.58 and 0.66 depending upon the stability of the atmosphere. If the correct value is assumed to be within these limits, the extreme error is likely to be within ±4%, Linsley et al (1975). The estimation of evaporation very much depends upon accurate evaluation of net radiation.

Estimation of Reservoir Outflow

The total outflow from a reservoir is sum of discharge through spillway, turbines, undersluices and leakage through dam:

$$Q = Q_{sp} + Q_{tb} + Q_{us} + Q_l \qquad (7)$$

where

Q_{sp} = discharge through spillways ,

Q_{tb} = discharge through turbines,

Q_{us} = discharge through undersluices

Q_l = discharge through leakage from dam

DISCHARGE THROUGH SPILLWAY UNDERSLUICES

The discharge through spillway can be computed either by using hydraulic formulae or by using result of laboratory model testing. The discharge through spillway can be computed using following formula.

$$Q_{sp} = C_{sp} \; C_q \; b_{sp} \sqrt{(2 g h^{1.5})} \tag{8}$$

Where

C_{sp} = submergence coefficient,

C_q = discharge coefficient for spillway,

b_{sp} = width of the spillway

h_{sp} = head over crest of spillway outside the zone of of the draw down

Under the free flow conditions, the discharge of an ogee spillway is given by

$$Q_{sp} = C \, (L - k \, n \, H) \, (H + h_v)^{3/2} \tag{9}$$

Where C is the coefficient of the weir, L is the clear crest length, n is the number of end contractions, H is the head over spillway, and h_v is head due to velocity of approach. In the metric units, the value of c varies from 2.21 at the discharge head to 1.71 at very small heads.

Along with spillways, reservoirs are also provided with low level outlets for releasing water when the reservoir water level is low. These outlets behave as orifices and the discharge through them is given by

$$Q_{or} = C_{or} \; e \; A \sqrt{2gh} \qquad (10)$$

Where C_{or} is the submergence coefficient for semisubmerged or submerged orifices, e is a factor which accounts for jet contraction and difference between actual flow velocity and idealized flow velocity, A is the cross section area of the orifice, and h is the head at the orifice measured from the center of orifice. The discharge coefficients can be obtained by hydraulic considerations or they can be determined from laboratory model tests or field calibrations. While conducting the model tests, one should properly consider the situations like characteristics of approaching flow, lateral discharge estimation will arise if the actual field conditions are not considered or the discharge coefficient is wrong. The project authorities prepare tables giving discharge through gated spillways for various gate openings. Linear interpolation is sufficient for intermediate values.

LEAKAGE THROUGH DAM

This component of outflow consists of loss of water from the reservoir on account of leakage through the body of the dam as well as through gates and spillways. It is not easily possible to relate these losses with a measurable quantity. For example the losses through the gates or values of undersluices depend upon their design, installation and maintenance. A simplifying assumption which is usually made in practice is that these losses linearly vary with the reservoir level. In general, the amount of water lost due to these reasons varies between 0.5% to 4% of the total discharge through the structure.

Computation of Groundwater Flow

A reservoir also experiences subsurface flow from or towards the aquifers though the magnitude is very small compared to the surface water inflow. The amount of this flow depends upon the physiographical features and soil characteristics in the vicinity, and the position of water table. Assuming homogeneous condition, the flow can be computed by the Darcy Law :

$$I_g = b\,d\,k\,\frac{h_1 - h_2}{L} \qquad (11)$$

where,

b = base width of flow

d = depth of flow

k = horizontal permeability coefficient (m/day)

h_1, h_2 = water levels at two sections across the underground current at a distance L apart (ref. fig.2).

Estimation of Change of Storage

The change of storage component of water balance equation represents the change in the reservoir storage during the period of computation. As explained by Ferguson and Znamensky (1981) this term can be expressed as a sum of four components.

$$\Delta S = \Delta S_w + \Delta S_{rm} + \Delta S_{bs} + \Delta S_g \qquad (12)$$

where,

ΔS_w = change in storage in reservoir,

ΔS_{rm} = change in channel storage of all those streams which directly debauch in the reservoir between the gauging site which lies just upstream of reservoir and the rim of reservoir.

ΔS_{bs} = change in storage in the banks of the reservoir.

ΔS_g = change in storage because some ice is left on the

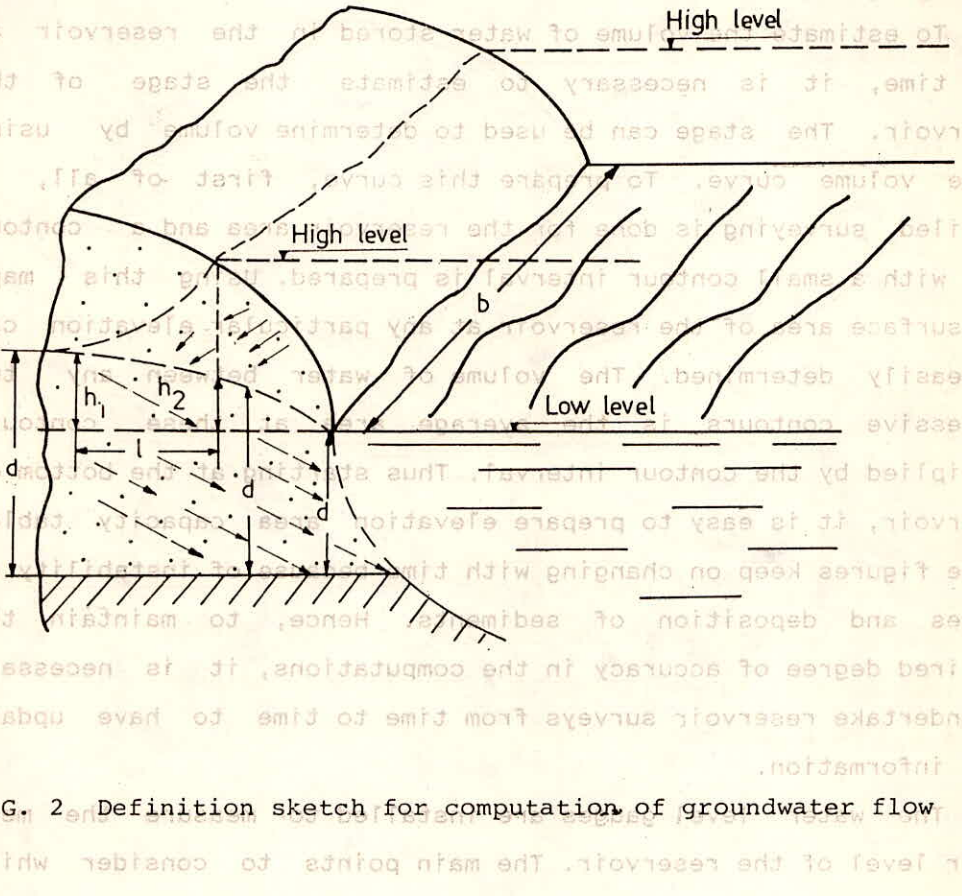


FIG. 2 Definition sketch for computation of groundwater flow

reservoir banks during winter which melts and flows back in summer.

Out of these four, the first component is the most important. The last component may have to be considered only for very few Indian reservoirs.

Estimation of Volume of Stored Water

To estimate the volume of water stored in the reservoir at any time, it is necessary to estimate the stage of the reservoir. The stage can be used to determine volume by using stage volume curve. To prepare this curve, first of all, a detailed surveying is done for the reservoir area and a contour map with a small contour interval is prepared. Using this map, the surface area of the reservoir at any particular elevation can be easily determined. The volume of water between any two successive contours is the average area at these contours multiplied by the contour interval. Thus starting at the bottom of reservoir, it is easy to prepare elevation area capacity table. These figures keep on changing with time because of instability of shores and deposition of sediments. Hence, to maintain the required degree of accuracy in the computations, it is necessary to undertake reservoir surveys from time to time to have update the information.

The water level gauges are installed to measure the mean water level of the reservoir. The main points to consider while installing these gauges are the shape of the reservoir the types of fluctuations that it experiences due to winds etc. and the ease in installation observation and maintenance of these gauges. Generally, it is required to locate the gauges along both banks (in the upstream direction from dam) of a reservoir. Special care must be taken of the area when the reservoir influences the stage of the river unless the storage in this zone is less than 5-10% of the total accumulation.

When wind blows over a reservoir, it applies shear stress on the water surface and thereby it tries to carry water along with it. This leads to a redistribution of water in reservoir, there will be greater storage in the down wind direction and lesser water in the upwind direction. Changes in the wind direction and/or magnitude of wind leads to fluctuations in the water level. The following equation (Ref. figure 3) can be used to compute the change in stage due to wind.

$$\Delta h_w = (3 + d_w) \frac{u^2 . l}{d_m} (\cos \lambda) 10^8 \qquad (13)$$

where u is the wind speed in m/s, l is the distance in meters between two points for which h_w is to be computed, d_m is the mean depth of reservoir in meters between these two points. λ is the angle between wind direction and the line joining these two points, and d_w is the mean wave height.

To compute the mean water level in presence of these fluctuations it is necessary to determine the location of equilibrium axes where the water level fluctuations due to wind generated shear are minimum. Once the change in water storage has been determined using the equation (13), the changes in water volume in a subarea can be determined by multiplying by the corresponding areas. The equilibrium axis is determined at the division of sub areas of positive and negative change of water volume. The direction of this axis is perpendicular to the wind direction. The position of this axis should be found for eight main directions, i.e., N,NE, E.. The point where the longitudinal axis of the reservoir crosses the equilibrium axis perpendicular to a given wind direction is the best location for a stage gauge. At these points the stage will be closest to mean reservoir level. It has been recommended to locate the gauge near the equilibrium

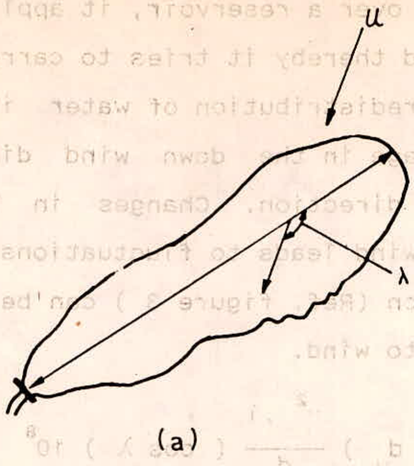


FIG. 3(a) Computation of fluctuation of water level in a reservoir

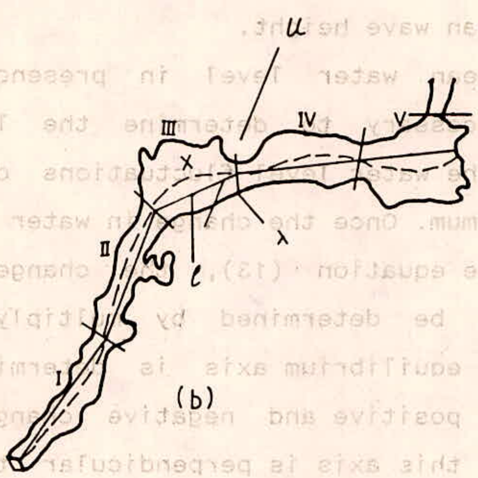


FIG. 3(b) Computation of fluctuation of water level due to wind in a reservoir when wind directions are changing axis when stage gradient due to wind effects exceeds 15-20 cm.

Errors in water Balance Computation

From the theoretical point of view, the various components of the water balance equation should sum up to unity. However, it is not possible to exactly estimate or measure the various components and thus the term δ was introduced in equation (1) to take care of the residual error. To avoid the propagation of errors, it is necessary to estimate the individual components of the water balance equation independently. The errors in individual components may be positive or negative and hence they may also tend to balance. Therefore, a small value of the error component does not indicate that the errors in estimation of individual components are small. The purpose of error analysis is to assess the correctness of the estimates and their sensitivity.

If the error in estimating individual water balance components are δ_1, δ_2, ...δ_n then it is recommended that the maximum value of error should not exceed the square root of sum of error of individual components, or

$$\delta < \surd (\delta_1^2 + \delta_2^2 + \ldots\ldots\ldots + \delta_n^2)^2 \tag{14}$$

If this criterion is not satisfied then it is required to re-evaluate the estimation procedure and measurements of individual components. Since the magnitude of different components vary widely, percentage errors in them will also vary over a large range. This variation also depends upon the time period of computation. As this period increases the magnitude of error in various terms which represent inflow and outflow to and from the reservoir also increases. However, the error in the term representing change of storage tends to reduce with increase in time period. The aim of any water balance study is to minimize the errors associated with different components of water balance equation. This requires an assessment of the sensitivity of various water balance components. This will depend upon duration of computation period, climatic conditions, physiographic factors and season of year. Different components may become significant in different seasons of year. For example, during summer months, inflows to the reservoir may be very small and evaporation quite large while during the monsoon period, the situation may be just reverse. Hence, the existing measurement network may have to be expanded in many cases. This requires a careful study and a final decision should be based upon the network analysis for required degree of accuracy and the finances available.

REFERENCES

1. Baumgartner,A., and E. Reichel(1975), World Water Balance, Elsevier Publishing Company, Amsterdam.
2. Fergusion,H.L., and V. A. Znamensky, Method of Computation of the Water Balance of Large Lakes and Reservoirs, Studies & Reports in Hydrology 31, Unesco, 1981.
3. Herschy,R.W.(Editor), Hydrometry, Principles and Practices, John Wiley and Sons, New York, 1978
4. IASH (1970), Symposium on World Water Balance, Publication NO. 92, IAHS-UNESCO-WMO.
5. Linsley,R.K., et al (1975), Hydrology for Engineers, McGraw Hill Book Company,Auckland.
6. Sokolov,A.A. and T.G. Chapman (1974), Methods for Water Balance Computations, The Unesco Press, Paris.
7. UN(1974), Manual for the Compilation of Balances of Water Resources and Needs, The United Nations.
8. Unesco(1974), Survey on Water Balance of Lakes and Reservoirs of the World, Unesco, Paris.
9. Vander Beben,A., and A. Herrmann (ed) (1985), New Approach in Water Balance Computations, IAHS Publication No. 148.
10. Vikulina,Z.A. (1970), 'Methods for computation of water balance of reservoirs', in Symposium on Water Balance, Publication No. 92, IASH.
11. WMO (1974), Guide to Hydrological Practices, WMO Publication No. 168 , Geneva.

FLOOD FORECASTING

INTRODUCTION

Floods have been responsible for untold miseries in major portions of the world since time immemorial. One or the other part of Bangladesh , India and Pakistan experiences flood every year. During the monsoon season, when about 80% of the total annual runoff occur in this region, floods of varying intensities are experienced in one or the other part of the countries.Nepal and Srilanka also suffer from flood problems. The heavy rain in almost all the SAARC countries results in problems such as land sliding , drainage congestion etc.

The flood management techniques are broadly classified into "structural" and "non-structural" measures. The structural measures are generally very popular but in the recent years, the importance of non-structural measures has been duly recognised. The loss of human life and property can be reduced to a considerable extent by giving reliable advance warning about the incoming floods. The people could be moved to safer places in an organised manner as soon as the flood warnings are received. Valuable movable property and cattle could be saved by shifting them to places of safety. The hydrological forecasts are equally important for the efficient operations of the various water resources projects.

DEFINITION OF FLOOD FORECASTING

Flood forecasting may be defined as "the process of estimating the future stages or flows and its time sequence at selected points along the river during floods". Flood forecasts refer to prediction of the "crest and its time of occurrence" and logical extension to the stages of river above a specified water level called the "Warning Level". This warning level is generally 1 metre below the Danger Level fixed in consultation with the beneficiary i.e. the concerned state authorities.

The utility of forecast is dependent on both accuracy and the warning time. The entire operation of the "Flood Forecasting Service" has to be planned around a time-factor keeping in view the following factors :

i) Availability of Operational Data;

ii) Adoption of appropriate techniques for formulation of forecast; and

iii) Dissemination of Forecast.

CLASSIFICATION OF RIVER FORECASTING

Depending upon the length of the period covered by forecast, it can be identified in following three groups.

i) short term,

ii) medium term, and

iii) long term

Short term forecasts of several hours or days provide flood warning and are used to warn the people likely to be affected by inundation, to operate dams and emergency flood ways and to keep vigil on the engineering on and along the rivers.

Medium term forecasts of several days or weeks are used to plan or modify operating procedures keeping in view the storage available and the water uses comprising irrigation, hydro-power generation, navigation and domestic water supply etc.

Long term streamflow forecasts of several months or a full season are used to plan seasonal utilisation of water likely to be available and for chalking out appropriate and periodic regulation schedule to match with the plan of utilisation.

The river forecasting can be classified as shown in Fig.1.

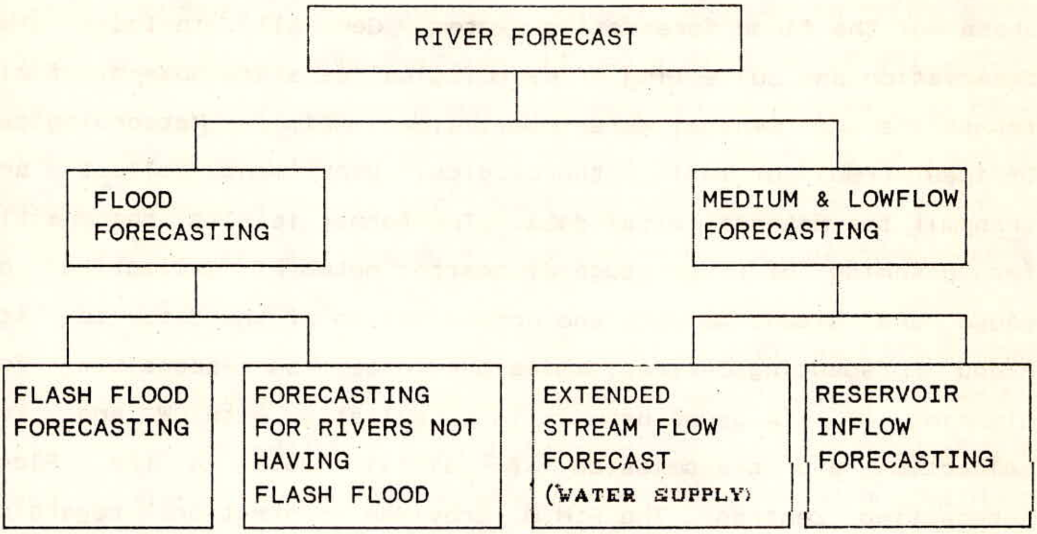


Fig. 1 : Classification of River Forecasting

FLOOD FORECASTING SYSTEM

The five important phases of a flood forecasting system are:

1. observation and collection of hydrometeorological and hydrological data from various stations;
2. transmission of data;
3. processing and analysis of data and formulation of forecasts;
4. dissemination of forecast; and
5. review and updating of the forecasting system.

The various phases are schematically illustrated in Fig.2. and each phase is briefly discussed here under.

Data Collection

The observation and collection of various hydrological and hydrometeorological data is the first and the most important phase of the flood forecasting system. Generally, in India the observation and collection of hydrological data are done by field formations of Central Water Commission. Flood Meteorological Offices (FMO) of India Meteorological Department collect and transmit the meteorological data. The former is also responsible for planning of river gauge/discharge network, collection of gauge and discharge data and communication of the data to its Flood Forecasting Centres, while the latter is responsible for planning of rain gauge network in consultation with CWC and for collection and transmission of rainfall data to the Flood Forecasting Centres. The F.M.O. provides information regarding general meteorological situation, rainfall amounts of last 24 hours and heavy rainfall warning for the next 24 hours for different regions and quantitative precipitation forecast for various river basins to the concerned flood forecasting centres of Central Water Commission.

The hydrological data are collected everyday and utilised by flood forecasting offices for formulation of forecasts during monsoon period. Similarly, the meteorological data including warning & general synoptic situation and weather forecast are generally being supplied by FMO to the Divisions and Sub-Divisions of Central Water Commission concerned daily by telephone, failing which the information are being collected by the special messengers of CWC field unit from the FMO Office.

Data Transmission

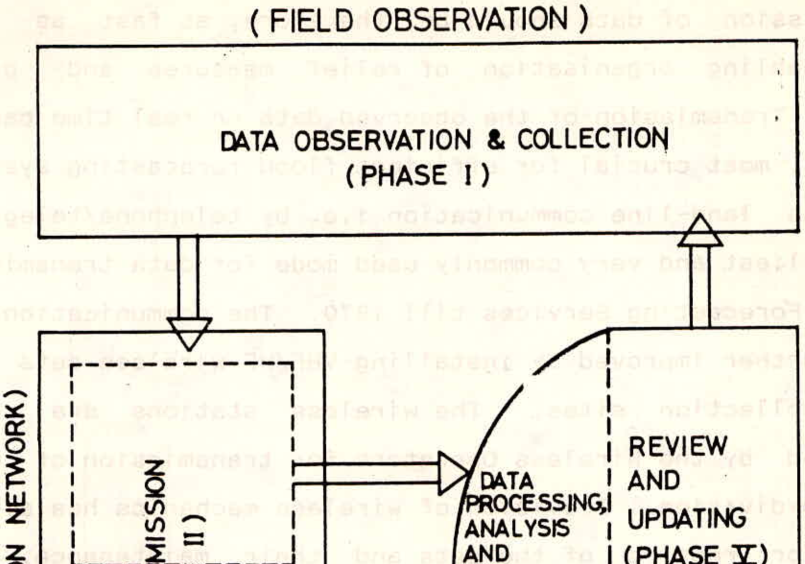


Fig. 2 - VARIOUS PHASES IN FLOOD FORECASTING

Transmission of data on real time basis from the hydrological and hydro-meteorological sites to the Flood Forecasting Sub-division/Division is a very vital factor in flood forecasting. Time is of essence in the whole exercise. Transmission of data should be, therefore, as fast as possible for enabling organisation of relief measures and protective steps. Transmission of the observed data on real time basis is, in fact, most crucial for efficient flood forecasting system.

The land-line communication i.e. by telephone/telegram was the earliest and very commonly used mode for data transmission in Flood Forecasting Services till 1970. The communication system was further improved by installing VHF/HF wireless sets at the data collection sites. The wireless stations are generally operated by the Wireless Operators for transmission of data to the Sub-division. Provision of wireless mechanics has also been made for repairs of the sets and their maintenance. Modern uptodate telecommunication techniques have been introduced in the Upper Yamuna upto Delhi. Planning, operations, maintenance and improvement of the communication network is looked after by CWC officers and supporting staff. Further improvements in the CWC telecommunication system are under execution.

Data Analysis and Forecast Formulation

After receipt of the hydrological and hydro-meteorological data at the sub-divisions, the data are compiled, scrutinised and analysed by Engineers/Hydrometeorologists engaged in this work. The system of data processing before use in forecast formulation has been introduced to prevent chances of errors. Many forecasting centres have been provided with micro-computer facilities for data processing.

The next important step is the formulation of forecast. In fact, the analysis of data and formulation of forecast is a very important stage in the process of forecasting system.

The various flood forecasting centres are using different forecasting models, based on availability of hydrological and hydrometeorological data, the basin characteristics, computational facilities available at forecasting centres, warning time required and purpose of forecast. However, some of the common methods being used by various centres are given below:

(i) Simple correlation-based on stage-discharge data.

(ii) Co-axial correlation-based on stage, discharge and rainfall data etc.

(iii) Flow Routing.

(iv) Hydrologic models.

The forecasts obtained from the correlation diagrams or mathematical models etc. are modified as necessary to arrive at a final forecast based on the prevailing conditions in the river. This requires intimate knowledge of the river by the persons responsible for forecasting. Forecast once issued is further modified and revised forecasts issued, if necessary, on the basis of additional informations received after the initial forecast was made.

However two most important factors in the use of a particular method for flood forecasting are the data availability and the lead time available .The classification of flood forecasting methods is illustrated in Figs. 3 and 4.

Dissemination

The final forecasts are being communicated to the administrative and engineering authorities concerned of the state and other agencies connected with the flood protection and management work on telephone or by special

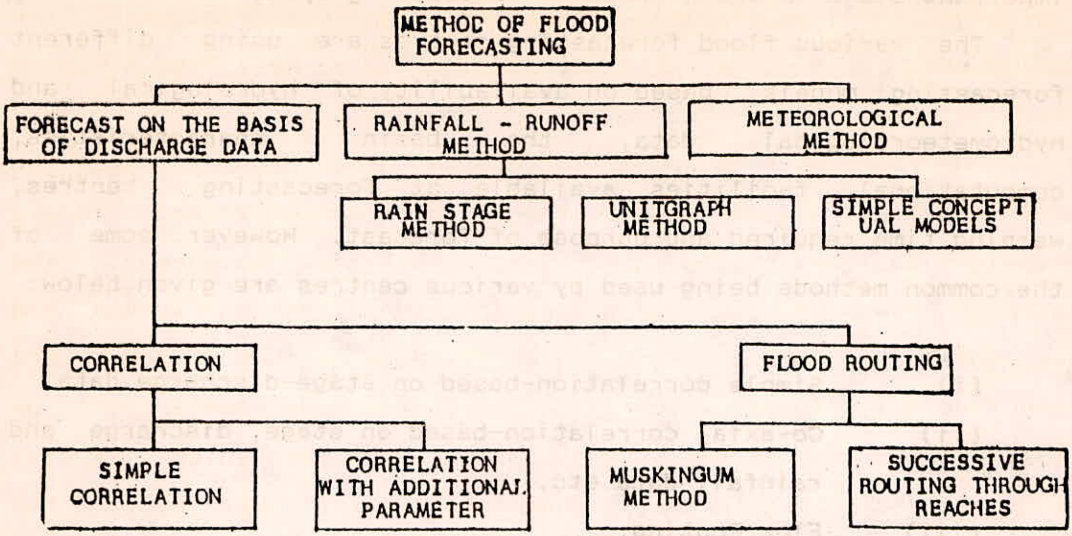


Fig.3 - METHOD OF FLOOD FORECASTING

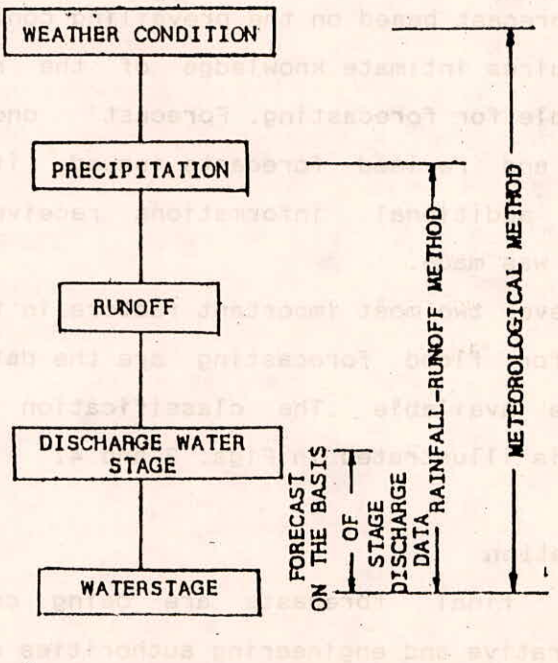


Fig. 4 - METEOROLOGICAL METHOD

messenger/telegram/wireless depending upon local factors like vulnerability of the area and availability of communication facilities etc.

On receipt of flood forecasts, the above agencies disseminate flood warnings to the officers concerned and people likely to be affected and take necessary measures like strengthening of the flood protection and mitigation works and evacuation of the people to safer places etc. before they are engulfed by floods. Generally, the State Governments set up control rooms at States and District Headquarters which receive forecasts and then further disseminate the flood warning to the affected areas and organise relief as well as rescue operation. Flood forecasts are also passed on to the All India Radio, Doordarshan and the local newspapers. It must be noted that the ultimate efficiency of the whole flood forecasting and warning system is only as good as the weakest link in the chain between the forecast agency (CWC in this case) and the public who need to respond. This has often been a somewhat neglected part of the total flood warning process. The many potential benefits in improving flood forecasting may not really materialise if the dissemination link is unnecessarily inefficient. Under the existing setup, however, this most important link is in the hands of the State Government agencies to implement even though C.W.C. is vitally interested in this step.

SOME PRACTICAL ASPECTS OF FLOOD FORECASTING

When a forecast is issued, public in general are not aware of the effect of particular level in the concerned area. The level information should be translated into its effect on the surroundings. It should be described with reference to the previous historical flood marks and flood events in the area. Prominent marks at various places should be indicated so that they gain confidence in the forecast. These guide posts should be brought to the notice of general public. In the event of real danger due to high floods proper arrangement must be made to keep the public well informed and effort must be made to evacuate them to safer places which are identified before hand.

To have a perfect forecast all the five basic functional components of flood forecasting mentioned below are equally important.

i) Reporting Network;
ii) Data Collection and Processing Facility;
iii) Forecast Preparation Centre;
iv) Forecast Dissemination Facility, and
v) Forecast Procedure Development Team.

Failure of any one of them will badly dislocate the system. The success of the system will really depend on how smoothly the various functional units run to achieve the following three objectives;

a) The loss of time in transmission of data, its processing and analysis , formulation of forecast and dissemination of the same is minimised.
b) The quality of data is ensured and necessary checks applied at as many points as possible to avoid the errors to the maximum extent.
c) The forecast is formulated with the help of the most appropriate model using the correctly defined boundary conditions for the model under the current situation.

The best possible forecast can be formulated only when the above objectives are achieved by the forecasting system. However, considerable practical difficulties are encountered in the operation of the system. These problems can be clearly identified from the three objectives described above, and the same are discussed briefly in the following sections.

Delay in Forecast

Some of the factors which are responsible for the loss of time and hence the delay in issue of forecast are:

a) failure of communication system;

b) processing of huge basic data;

c) time consuming analytical techniques;and

d) complicated models for formulation of forecasts.

Failure of Communication System

It is one of the major factors which delays the transmission of data from the observation point to the control rooms where these data are to be processed. The disruption of road/railroad traffic, particularly during heavy flood creates problems where data are sent through messengers. The disruption of telephone lines etc, as a result of storm etc. renders such communication system useless at the time of need. Power breakdown, sudden trouble with the wireless sets and damages to masts also create serious problems in timely transmission of data. These problems are very frequent in nature and , therefore it is necessary that the forecasting organisations equip themselves to meet such eventualities by having suitable arrangements to serve as alternative communication system. In India, the flood forecasting units generally have understanding with other agencies (such as police, customs departments etc. who have their own communication network) for their use as regular mode or as as an alternative in such situations.

Processing and Analysis of Data and Forecast Formulation

The processing of huge data, their analysis, and formulation of forecast consumes definite amount of time which depends upon:

a) the number of variables to be used in operational forecasts and their frequencies;

b) the technique used for analysis of these data (such as the method for assessment of aerial distribution from the point rainfalls, the model for time distribution of the amount of direct runoff etc);

c) the structure of the models used in the forecast formulation ; and

d) the computing facilities available at the forecasting centre.

The time required in processing, analysis and formulation of forecasts can be considerably reduced by using a reasonably fast computing facility such as a small size computer/micro processor. In the absence of such facilities, it would be necessary to adopt the techniques/models which are:

a) as simple as possible;

b) capable of achieving an accuracy necessary for the purpose; and

c) expressed in form of functions easy to calculate with the help of available computing facilities.

Sources of Errors in Forecast

The forecast issued in time is not enough. It should also be as accurate as possible. The three main sources of error in forecast are:

a) error at source i.e. error in observed data.

b) error during transmission, and

c) the computational error.

ERRORS AT SOURCE

The errors at source may be either the instrumental error or the observational errors or the copying error. The observational and the copying errors can be avoided to a great extent by proper supervision and checks at different levels at frequent intervals. The instrumental errors may be classified in two groups, viz; (i) errors of sudden or emergent nature, and (ii) errors which creep slowly over long time. The errors of the first type are because of sudden problems with the equipments e.g., washing away of gauge post and error during fixation of new gauge posts by staff members not fully trained for the job. A careful processing of data might reveal such errors. Besides, arrangements are generally made for such situations. For example, gauge marks are painted on nearby permanent structures (such as bridge pier, steps of the ghat etc.) near the proper gauge sites. Similarly, the nearby gauge posts/gauge marks of other agencies (state Governments, Railways etc.) are correlated with the proper gauge sites.

The error of second type are rather difficult to be noticed during the 'routine data processing'. Such errors in the gauge data, for example, may be because of slow settlement of gauge posts in sandy beds or in discharge data, due to deterioration in rating of the current meter. These errors can be detected by frequent checking.

The other hydro-meteorological and hydrological equipments (raingauges, etc.) are also liable to similar errors.

Yet another source of error is due to communication gap. For example, when the gauge post at the proper site is washed away, the observer moves to alternative site for the observation and transmits the data of the new location without mentioning the fact (i.e. the change in location of the observation) to the control room. As a result, the variation in the water level at the two location goes unnoticed and hence the error. Such errors are mainly because of lapse of sufficient training to field staff, and they can be avoided and detected by proper training to the concerned officials.

ERRORS DURING TRANSMISSION

The errors during the transmission (which are mainly because of slip of tongue, slip of pen and absent-mindedness etc.) can be minimised by adhering to the procedure laid down for transmission of data. Further, any error noticed during the processing and the analysis should be immediately checked and rectified. Proper training of the personnels engaged in transmission of data is a must.

COMPUTATIONAL ERRORS

The computational errors are of two types : the errors associated with the computational instruments such as calculators etc., and the human error. Such errors are quite possible and to avoid them, it is necessary to check the formulated forecasts at two or more levels preferably by using different approaches. For example a forecast formulated with the help of a co-axial diagram can be rechecked with the help of a mathematical equation representing the co-axial diagram. Further, it will be desirable to have another check by some other technique. A water profile diagram - a very basic and rather crude tool for forecasting, may also be used before the issue of the formulated forecast. Such checks will considerably reduce the possibility of computational errors.

Unexpected Situations

A very difficult situation arises when the official responsible for formulation of forecast is handicapped because of:

(a) non-availability of all the desired data/information; and

(b) deviation from the defined boundary conditions.

NON-AVAILABILITY OF ALL REQUIRED DATA IN TIME

The non-availability of the desired information at the time of forecast formulation is a very common problem. This generally results in either delay in formulation of forecast (when the receipt of additional information is awaited) or in formulation of forecast with computed data. Obviously, the delay in formulation of forecast will cause loss of precious time which is not desirable. On the other hand, the forecast formulated with computed data may affect the accuracy of forecast.

Therefore, it is necessary that the alternative methods/techniques are available so that the forecast could be formulated using the available limited data with known degree of accuracy.

DEVIATION FROM DEFINED BOUNDARY CONDITIONS

A not so common but very important phenomenon is the situation when there is deviation from the defined boundary conditions of the model. Some of the examples of such situations are:

(a) Breach in the flood embankments of river.

Such a situation occured during 1986 in the river Gandak when there was a breach near Pipra Piprasi and river Burhi Gandak when the embankments breached near Samastipur. Under such situations, the commonly used model for forecast do not work any more and the necessary informations about the condition of the breaches etc. are to be collected round-the-clock and duly considered while formulating the forecast.

(b) Rain of very high intensity at locations in between the base and the forecasting stations.

This becomes very important when the intermediate catchment is considerable and the same is not incorporated with due weightage in the model.

(c) Unexpected regulation of the control structures.

Such a situation is very often encountered in forecast of sites located just upstream of the control structure or when the base station is located downstream of the control structure. A sudden closure/opening of gates without advance information to the forecasting centre adversely affects the forecast performance.

The conditions arising out of such situation can be included in the forecasting model in a very limited way. Therefore, they have to be carefully examined and their impacts judiciously incorporated in the model as the situation warrants. Alternatively some other methods are to be identified and adopted depending upon the nature of the problem. Hence, it is necessary that the personnels at the forecasting centre are duly qualified, trained and experienced and are capable of taking immediate decisions and act accordingly.

One more important aspect which needs to be looked into is the definition of the responsibilities of personnels involved in forecasting process and the organisational set up.

ORGANISATIONAL SET UP

The discussions on the various problems enumerated in the earlier sections repeatedly refer to well defined functional units at the forecasting centre. A forecasting centre should consist of following five well defined functional units.

a. Reporting network headquarters.
b. Data bank.
c. Forecast preparation unit.
d. Forecast dissemination centre.
e. Co-ordination, research and development unit.

Fig. 5. illustrates the functional relationship between all the five units.

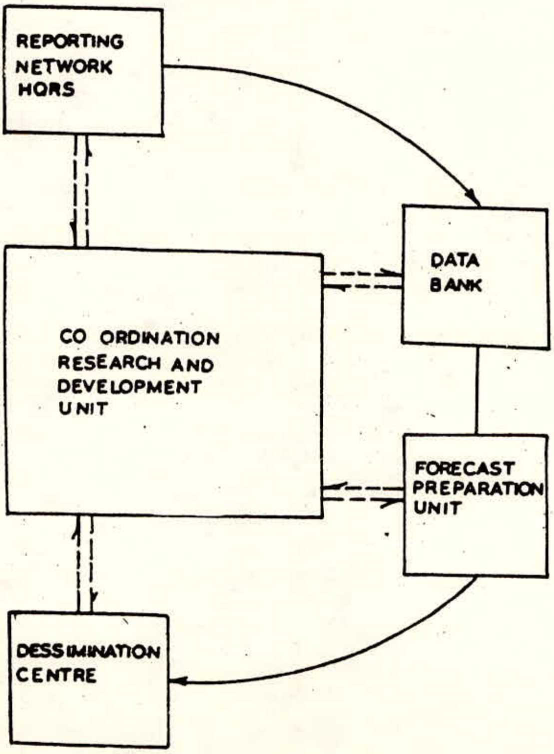


Fig. 5 – FUNCTIONAL UNITS OF A FORECASTING CENTRE

WATER QUALITY AND ITS MODELLING

Introduction

The subject of water pollution is a big challenge for hydrologists and environmental engineers. It has become even bigger challenge in recent years and still is in a rapid state of development hence a flood of literature is being generated, on the subject.

As part of a general concern for the environment water quality became the important water resources issue in the 1970. Obvious pollution, existing for decades, had been ignored to pursue water quality ventures. Suddenly, the situation appeared to be worse and it was. Population growth and urbanization overloaded municipal treatment plants and domestic waste waters were discharged with little or no treatment. Most industries in 1950s and 1960s under pressure to expand production to meet high customer demand, dumped their wastes raw in nearby lakes and reservoirs. Manufacturing plants within cities discharged to municipal sewers, but treatment plants, built in 1930s and 1940s were incapable of handing industrial wastes. Excessive use of fertilizers, raising of cattle worsened the situation. Many of these operations were sited on lots adjacent to streams so that the rainfall washed away the manure. Mining and petroleum operations were also major polluters. The quantity of waste waters from all these operations exceeded the self purification capacity of many rivers and streams.

In this lecture an over view of water quality characteristics data requirement mathematical models and classes of such models is given.

WATER QUALITY CHARACTERISTICS AND CLASSIFICATION

Water pollution manifests itself through changes in water quality. Quality water is water whose characteristics make it suited to the needs of the user. Acceptable water quality is therefore dependent upon the requirement of many kinds of water consumers. Characteristics that make water unsuitable to one water user may be unimportant, or even desirable, to another (e.g. low dissolved oxygen levels are desirable in cooling waters used in steel mills since it decreases rust problem).

As a result of the fact that there are many water uses (e.g. water supply, industrial irrigation, aquatic life and transportation) each having varying needs for aspects of water quality, and many types of water contamination. The problem of defining water quality is nontrivial. Nevertheless, an over view characterization is in terms of:

- * Biological -where pollutants includes bacteria and viruses:
- * Chemical -where pollutants may be organic, inorganic and radiological : and,
- * Physical -where pollutants include thermal effects and suspended solids.

It is appropriate to further examine some aspects of the above mentioned categories of pollutants since they will be relevant in how they are modelled in a mathematical framework. The variation in the mathematics may be with respect to the estimation of sewage loadings, the pollutant behaviour in the water body receiving the pollutants, and even to the point where only a surrogate (or pseudo measure) of the pollutant is modelled.

Presented in the sections to follow are aspects of the individual categories of pollutants.

Biological Quality

ENTERIC BACTERIA

Enteric bacteria pertain to those arising in the intestinal tract of animals, including humans. The enteric bacteria may be further sub-divided into two classes of bacteria, namely.

i) Pathogens - These bacteria are responsible for water borne diseases such a typhoid, dysentery cholera and gastroenteritus. To be used for uses such as water supply for drinking, these bacteria must not be present, however, they are very hard to find because of their small size and so are not generally modelled.

ii) Coliforms - These bacteria also arise in the enteric tract but, unlike pathogens, they are harmless. Nevertheless, they are highly useful as indicators of fascal contamination as they are in very large numbers (upwards of 400 x 10^9 per day are in human feces). The coliforms have been found to die off very quickly and at a similar rate to pathogenic bacteria and thus have received widespread use as an indicator, or surrogate parameter of bacterial contamination. The efforts of water quality modelling have thus been focused on coliforms and their die-off rates.

VIRUSES

During the past 25 years more than 70 new enteric virus have been identified, all of which are found in human feces. Commonly - occurring examples include polio and hepatitis. The viruses are not well understood because of their extremely, small size (.01 x 10^{-6} m), which is beyond light microscopy. Even relatively sophisticated water treatment facilities are not fall-safe. For example, some virus pass through rapid sand filters, although 99 percent removal is possible with use of alum, floculation and settling.

There is definitely a need for improved methods of quantitative estimation of virus concentrations and easier methods of identification. It should be remembered that a possibility always exists that a water may be classified as potable by any of the afficial bacteria tests and still contain dangerous concentrations of viruses. There has been virtually no mathematical modelling of viruses. In receiving water bodies, dependence again being on modelling of coliform bacteria as an indicator of fascal contamination.

Chemical Quality

INORGANIC CHEMICALS

For modelling purposes, inorganic chemicals are typically sub-divided into :

i) Hazardous materials - examples include load arsenic, cadmium, nitrates. If these chemicals are present in large quantities they are poisonous. In lower concentrations, the chemicals are absorbed by fat tissue and interfere with the nervous system.

The tests for identification are difficult and expensive. Mathematical modelling of these chemicals is relatively complex because the stoichiometry (uptake, absorption, chemical exchange) must be reflected. Much work remains to be done in this area of water quality modelling.

ii) Nuisance chemicals probably the most important chemical in this category is phosphorus. The sources of phosphorus are typically man-derived arising from fertilizers and detergents. Phosphorus is frequently the limiting component preventing prolific algal growth. Extensive attention is being focused on the modelling of phosphorus in its component forms.

ORGANIC CHEMICALS

These chemicals are characterized by the presence of the carbon - carbon bond. They may be sub-divided into:

i) Hazardous - These include pesticides such as DDT (which is foreign to nature and carcinogenic, or cancer - forming and phenols. The modelling of these contaminants is at a fairly elementary stage.

ii) Nuisance - These chemicals are generally referred to as BOD, or biochemical oxygen demand. This type of modelling has been widely utilized in part because of its fundamental role in characterizing the dissolved oxygen budgets in the water body. In essence, the pollutant behavior comprises

Organic material	Microorganisms molecular oxygen from the water body	Stabilized compound

Physical Quality

The mathematical modelling of these pollutants is very much a function of the extent of the contamination. If the contamination is very small, the modelling is fairly straight - forward. However, when the contamination is considerable, the density of polluted water is no longer sufficiently like pure water and thus the pollutants affect the flow field of the water itself. In this latter case, the modelling become very complicated.

Water Quality Parameters to be Sampled

The water quality parameters that are measured in a sampling programme will vary with the location and purpose of the sampling programme. Analytical costs are very high. Therefore, only those data which will help answer the question(s) of interest should be collected. Preliminary manual sampling for initial characterization in the sampling programme. If warranted by the problem at hand, samples for specific organics such as PVB's or pesticides should be collected. Often the water quality parameters of interest are not necessarily specific compounds or elements but rather refer to general categories. For example, it is clearly impossible to sample for the several different organics in urban runoff or combine sewer overflow, rather, one must be content with gross indicators such as BOD or TOC.

Water quality parameters that might be of interest fall into seven classes; common constituents and indicators nutrients, organic indicators, trace elements, solids pathogenic bacteria indicators, and special parameters. Consideration should be given to both the dissolved and unfiltered portions of the appropriate parameters.

COMMON CONSTITUENTS AND INDICATORS

The common constituents and indicators include calcium, magnesium, sodium, potassium, silica, bicarbonate, fluoride, chloride sulfate, dissolved solids, specific conductance, alkalinity, hardness, pH, water temperature and dissolved oxygen. Of the common constituents and indicators, particular attention has often been given to chloride and sodium, which can be significant water quality parameters in urban runoff in area of snowfall. Salt from and deicing can result in ecological danage, contamination of ground water or surface water supplies, or damage to vehicles and highway structures.

NUTRIENTS

Nutrients originate predominantly from organic pollution, fertilizers, and automobile exhausts. The behavior of phosphorus and nitrogen species is quite different. For example, nitrate in fertilizers is highly mobile, phosphate, however, generally remains attached to soil particles during transport. The principal impacts of nutrients are their effects on the eutrophication of lakes and impoundments and on the productivity of rivers and estuaries. In order to arrive at an understanding of overall processes, nutrients (both phosphorus and nitrogen species) should be measured, nitrogen occurs in nature in five forms; elemental nitrogen, organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. All forms except elemental nitrogen are eventually available to plant life following transformations in the receiving water body. The concentration of nitrate is almost invariably minor in comparison to the concentration of nitrate. It is recommended that three analysis be considered; nitrate + nitrate, Kjeldahl nitrogen, and ammonia, of the phosphorus measurements, total phosphorus is the preferred measurement. Dissolved orthophosphate should also be run if necessary.

ORGANIC INDICATORS

The primary indicators of organic are biochemically oxygen demand (BOD), chemical oxygen demand (COD), total oxygen demand (TOD), and organic carbon.

Biochemical oxygen demand is a measure of dissolved oxygen deptetion by biological and chemical reactions. BOD is a laboratory measurement that may not present instream conditions. Chemical oxygen demand is a measure of inorganic and organic oxidizable materials, therefore, high loadings may result to a large degree from organic material which cannot be utilized by micro-organisms. The interest in organics is porimarily as a result of its utilization by micro-organisms. However, the ability of BOD measurements to reflect accurately bio 'degradable organics has been questioned as a meaningful measurement in urban areas in which runoff may contain significant amounts of toxicants. Colston in a study of urban storm waters at Durham, North Carolina, found BOD measurements to be highly erratic relative to COD measurements. This was believed due to inhibitory effects from high heavy metal concentrations and/or inherent problems with the standard BOD test.

The total oxygen demand test has the advantages of little interference by other substances. Expensive instrumentation is needed, however, and more materials may be oxidized than will actually exert a demand on receiving waters.

Total dissolved, and/or suspended organic carbon measurements have been recently used in lieu of BOD or COD. Organic carbon tests are especially applicable to small concentrations of organic matter. Like COD, and TOD, organic carbon measurements indicate more than just the easily degraded organic load.

BOD, TOD, COD and organic carbon measurements are not substitute tests, but rather provide independent measurements. No standard correlations among these parameters have been established for storm waters. No consensus of opinion regarding the relative importance of the foregoing measurements could be reached.

TRACE ELEMENTS

Automobile traffic and industrial activity as well as other factors can contribute heavy metals to land surfaces, which eventually end up in urban runoff. Trace element have a special affinity for transport by suspended sediment, suggesting that samples should be collected during periods of high suspended sediment concentration. The trace elements most commonly found in significant quantities are lead, zinc, cadmium, mercury, copper, arsenic, chromium, iron, nickel, antimony and maganese. Complete sampling of all runoff events for these metals is not warranted; but at least a few samples should probably be analyzed for each. Due to high analytic costs, samples should normally only be analyzed for total concentrations.

SOLIDS

Sediment transport is typically associated with and/or on channel degradation. In urban areas, sediments can also originate from dust and debris that accumulates on impervious surfaces and is subsequently washed off. Suspended sediment is important both directly, causing interference with sunlight penetration, increasing turbidity and siltation of fish spoawning beds; and indirectly as a transport mechanism for materials such as pesticides, heavy metals, nutrients, decomposable organics and bacteria.

The procedure used for measurement of particulates should be carefully spelled out when reporting the values obtained. Suspended residue is the most common measurements. The particulates which are included in this measurement will depend upon the filter used in the analysis and this factors should be included when reporting the results.

Knowledge of both the suspended and the settleable solids concentrations in urban runoff is often important. It is also often important to know how much of the pollutant load is attached at least to the settleable solids so that an estimate can be made of the fraction of the pollutant load which will ultimately settle to the bottom of a stream, lake, estoary water supply reservoir, etc. Chemical determinations on the supernatant of settled samples would be worthwhile. Settleable residue measurements might also be worthwhile when gravity separation is considered as a storm runoff treatment process. The voltatile fraction of the total suspended residue might also be determined, at least periodically, in order to estimate the fraction of the suspended load consisting of organic matter.

The neterogencity of runoff with respect to particulates suggests the need for manually sampled depth velocity integrated samples of suspended sediment including the bed load. Samples should occasionally be a problem. Automatic cameras may be useful for assessing the floatable particulate load.

PATHOGENIC BACTERIAL INDICATORS

Because parthogenic organisms present in urban runoff are of numerous types, few in number per type, and difficult to isolate, the coliborm organism that is more numerous and more easily tested for is usually used as an indicator organism. Focal coliform is that portion of the total coliform that is associated with the faces of worm blooded animals. Samples for coliform measurements should be collected manually due to the almost unavoidable cross contamination of these organisms by automatic samples.

SPECIAL PARAMETERS

A few analysis for selected, special parameters could beworthwhile. These parameters include oil and grease, phenols, selected pesticides, polychlorinated biphenyls (PCB's), cyanide, and any special parameter(s) specific to the area of interest based on land use and or industrial types.

MATHEMATICAL MODELLING - A GENERAL DESCRIPTION

Models can be defined as formal expression of the essential elements of the problem in either physical or mathematical terms. A problem has to be normally expressed verbally, in the first place. This is the first, preliminary but compulsory step in the building of a model. The term systems analysis, is sometimes used synonymously with modelling, but this does not seem correct. Systems analysis is defined as the orderly and logical organization of data into models, followed by their rigorous testing to provide validation and improvements.

Classes of Mathematical Models

So many classifications of mathematical models are given in the literature that it is not possible to include all these classifications. The classification of any model depends upon its uses. A pair wise comparison of models is given here.

RESEARCH MODELS AND MANAGEMENT MODELS

It is very difficult to distinguish the two from the point of view of usefulness. Management models are mostly used as management tools whereas research models are used as research tools. For example cutrophication models have been widely used as research tools in addition to its use for management. Similarly CO_2 climate model is at present more useful to make further research rather than as a predictive model.

DETERMINISTIC AND STOCHASTIC MODELS

In case of deterministic models the values are computed exactly whereas in the stochastic models the predicted values depend upon probability distribution. Mostly the models used in water quality and sediment routing are deterministic. It can be concluded from the literature that our experience in this field is not advanced enough to allow the use of stochastic modelling, although some attempts have been made.

COMPARTMENT MODELS AND MATRIX MODELS

In the case of compartment models the variables defining the system are quantified by means of time dependent differential equations whereas in case of matrix models matrices are used in the mathematical formulations. Mostly the models used in water quality are compartment type but some biodemographic geological models are matrix models.

REDUCTIONISTIC MODELS AND HOLISTIC MODELS

The difference between these types is that the holistic models use general principles whereas the reductionistic models include as many relevant details are as possible. In this field limited attempts have been made to use holistic models.

STEADY STATE MODELS AND DYNAMIC MODELS

In case of steady state models the variables defining the system are not dependent on time (or space), whereas in the case of dynamic models the variables defining the system are functions of time. Normally in water quality and sedimentation field steady state models do not find much use as they do not predict the time varying phenomena. Though there are some models which are steady state.

DISTRIBUTED MODELS AND LUMPED MODELS

In the case of distributed models the parameters are considered function of time and space and in the case of lumped models the parameters are within certain prescribed spatial locations and time, and are considered constants. Distributed models are used normally when large ecosystems are to be modelled. For the purpose of our studies lumped models are sufficient.

LINEAR MODELS AND NONLINEAR MODELS

In the case of linear models first order equations are consecutively used whereas in non-linear models one or more of the equations are not of the first order. In principle there is no difference between linear and non-linear models, only thing is that linear type has a simpler form than the non-linear type. Most of the environmental systems models contain nonlinear expressions such as hyperbolic or exponential expressions. With the advent of modern computer techniques there seems to be no reason to force such models into linearity for the sake of saving some milli seconds of computer time.

CASUAL MODELS AND BLACK BOX MODELS

In case of casual models inputs, state variable and output are interrelated, whereas in the other case the input disturbances affect only the output responses. In case of environmental modelling, an understanding of the system is required and hence casual modelling is normally used. The black box models do not contain any understanding of the system constituents and their relationship.

Components of Models

An environmental or ecological model consists, in its mathematical formulation, of five components.

1. External Variable
2. State Variable
3. Mathematical Equations
4. Parameters
5. Universal Constants

External variables also called forcing functions are variables or functions of external nature that influence the state of the ecosystem. The problem of modelling can be reformed as: if the values of some of the forcing functions are the input of pollutants to the system of rivers, addition or removal of fishery etc. Temperature, solar radiation and precipitation are also forcing functions, which at present, can not be manipulated.

State variables, as name implies define the state of the system. The selection of these variables is crucial but the choice is also obvious. If, for example we want to model the sediment deposit in reservoir, it is natural to include the sediment concentration and velocity of streams as state variables. When the model is used in the content of management studies, the values of the state variable predicted by changing the forcing function can be considered as the result of the model, as the model will contain relationships between the forcing function and state variables. Most models will consist more state variable than are directly required for the purpose of management.

The biological, chemical and physical processes in the ecosystem are represented in the model by means of mathematical equations. These are the relationships between two or more state variables and between forcing function and state variables. It is, however, not possible that one equation represents whole system, most of the processes have several mathematical representation.

The mathematical representation of processes in the system contain coefficients or parameters. They can be considered constant for a specific purpose or system. Many parameter values are known within limits. However, only a few parameter values are known exactly and hence it becomes necessary to calibrate others.

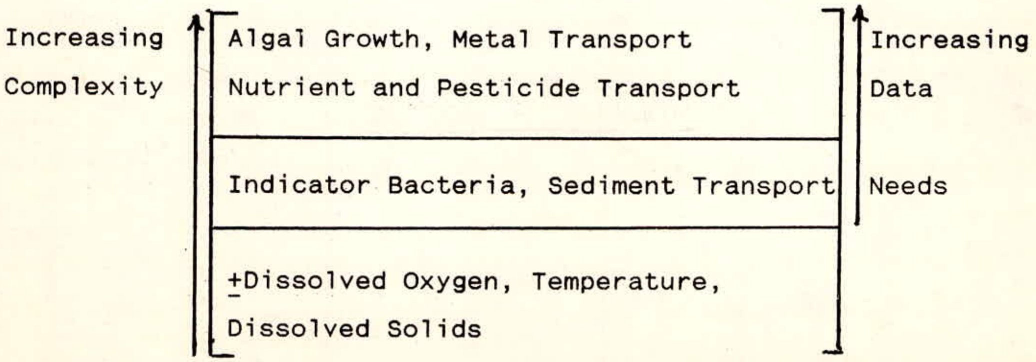
Most models will also contain universal constant such as gas constant, molecular weight etc. such constants are of course not subject to calibration.

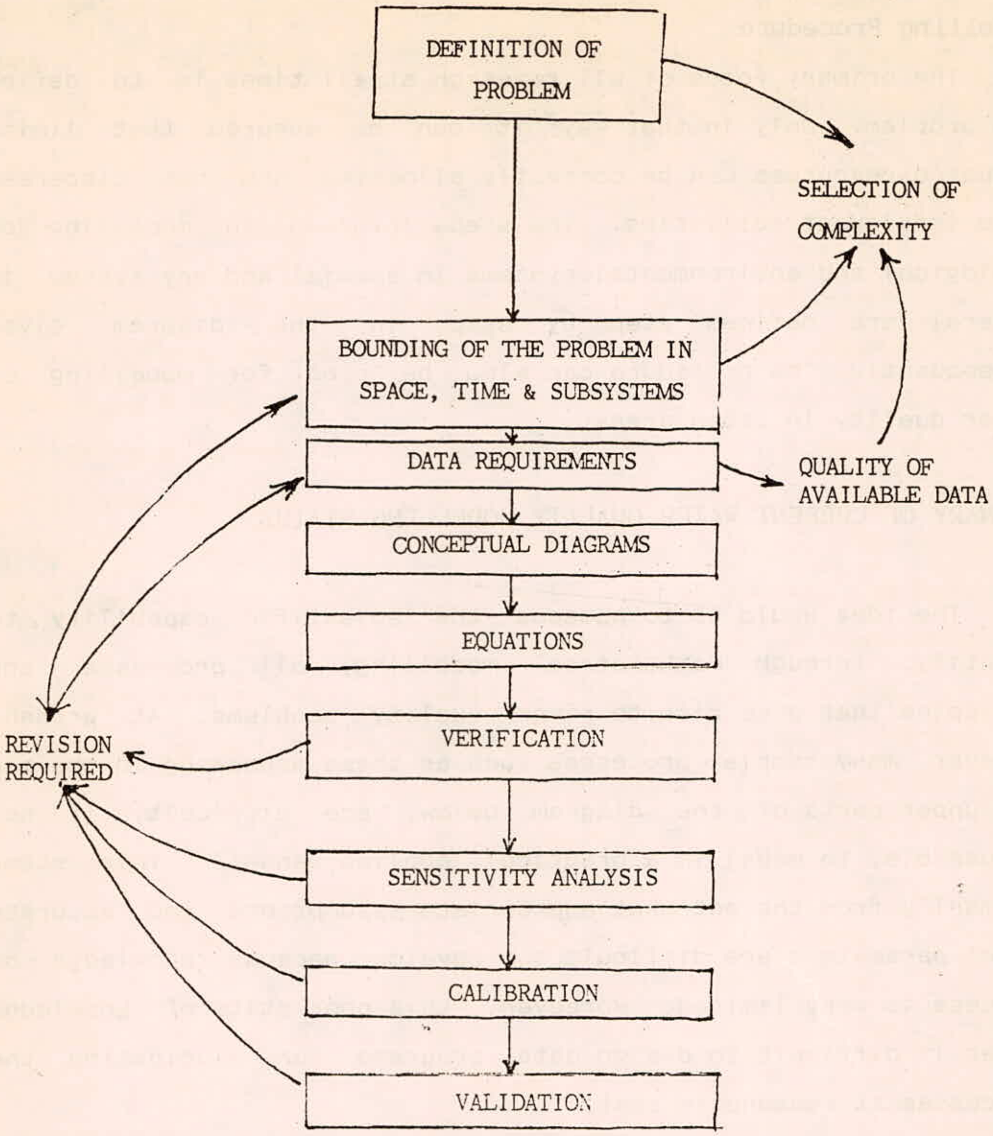
Modelling Procedure

The primary focus of all research at all times is to define the problem. Only in that way it can be ensured that limits research resources can be correctly allocated and not dispersed into irrelevant activities. The steps involved in modelling of ecological and environmental systems in special and any system in general are defined step by step in the diagram given subsequently The procedure can also be used for modelling of water quality in urban areas.

SUMMARY OF CURRENT WATER QUALITY MODELLING STATUS

The idea would be to possess the scientific capability to quantify, through mathematical modelling, all processes and variables that give rise to river quality problems. At present however, many complex processes such as these appearing in the mid and upper parts of the diagram below, are difficult, if not impossible, to model in a practical, applied sense. This stems primarily from the act that appropriate assumptions and accurate model parameters are difficult to develop because knowledge of process is very limited. Moreover, this poor state of knowledge makes it difficult to design data programs for elucidating the processes at reasonable cost.





MODELLIONG - PROCEDURE

Water quality data are difficult and expensive to collect and involve a number of considerations. Only data that are necessary to satisfy the objectives of the study should be collected.

WATER QUALITY MONITORING

River water quality problems stem basically from two factors, the natural hydrology of a river basin and the development and use of the land and water resources by human beings. Depending on the interrelation of these factors, a wide variety of quality problems can result. Each river basin, therefore, is unique and it follows that each one must be subjected to individual and intensive river quality assessment to provide a proper basis for judicious management of the land and water resources.

For a proper planning of water quality monitoring programme the following questions are generally need to be considered:

- * What are the objectives of the programme ?
- * From where samples are to be taken ?
- * Which determinants are of interest ?
- * When and how often samples are to be taken ?
- * What is to be done with the results ?

These questions provide a framework for defining measurement programmes. Results obtained from a programme should be regularly reviewed to decide if changes (e.g. of determinants or sampling frequency) in the programme are necessary.

DEFINING THE OBJECTIVES OF MONITORING PROGRAMME

It is an obvious point that the objectives of a programme should be clearly and precisely formulated by the user. If it is not done, in appropriate analytical data may well be provided and/or the user is likely to call for needlessly large or unduly small numbers of results. Further more, if the objectives are not precisely expressed, it will be difficult or impossible to decide the extent to which they are achieved.

It is suggested that analytical information should be requested on a regular basis only when the user knows beforehand that the results will be used - in a precisely known fashion - to answer one or more defined questions on quality. Requests for analysis based on the thought that the results may be ultimately prove to be useful should be avoided, particularly when - as is increasingly the case - analytical sampling 'effort is limited. There is an almost infinite number of analysis that might be useful in most situations, but it is completely impracticable to attempt any such comprehensive coverage. Therefore, selection from all the possible objectives and determinants is essential for a proper planning of monitoring programme.

As a further means of optimizing measurement programmes, the user should formulate his information needs as quantitatively as possible. As an extreme and perhaps rather artificial example of a badly defined requirement, consider the statement, to obtain information on the quality of river. Such a statement is almost completely useless as a basis for the design of a monitoring programme for the following reasons:

i) the determinants are not specified so that analysis required are not known;

ii) the particular river and the locations on the river are not defined so that in appropriate sampling positions may be chosen;

iii) no indication is given on the time scale or sampling frequency so that too few or too many samples may be collected and analyzed;

iv) as a result of all of the above lacks, there is no indication of the amount of data that will need to be processed and the nature of the data treatment so that appropriate data handling techniques can not be defined.

Users of analytical results must seek to avoid uncertainties such as those in the above example by careful and quantitative definition of every aspect of their requirements. Thus, an objective such as the above would be better expressed by a statement of the following form: 'to estimate each year the annual average concentration of ammonia ($NH_3 + NH_4$) at all river sites used for the production of potable water'. Appropriate statement of this type for other determinants of interest then provide a set of quantitative targets essential in optimizing the choice of sampling, analytical and data handling techniques.

OBJECTIVES OF GEMS/WATER

The fundamental objectives of the water quality monitoring system within the GEMS/WATER programme are to :

1. Assess the impacts of man's activities upon the quality of the water and its suitability for required uses.
2. Determine the quality of water, in its natural state, which might be available to meet future needs.
3. Keep under observation the source and pathways of specified hazardous substances.
4. Determine the trend of water quality at representative stations.

The first objective is met by the establishment of impact stations, the second by baseline stations, the third by either impact or baseline stations depending upon whether the hazardous substance is of artificial or natural origin, the fourth by trend stations.

Baseline stations are located in an area where no direct diffuse or point sources of pollutants are likely to be found.

They are used to establish the natural background level of variables, to check if no synthetic compounds are found in remote areas (e.g. DDT) to assess the long term trends of surface water quality resulting from global atmospheric pollution. Impact stations are situated in water bodies where there is at least one major use of the water, or which are greatly affected by man's activities. Four type of impact stations can be identified according to different uses of water:

a) Drinking water - at the raw water intake before treatment for drinking water.

b) Irrigation - at the water intake before distribution for irrigation

c) Aquatic life - river and lake stations representative of the general quality of the water body.

d) Multiple impacts - several water uses at the station and/or of the water body.

Trend stations are set up specially to assess the trends of water quality. They must be representative of a large area with various types of human activities. These stations should be more frequently sampled in order to increase the statistical significance of the average concentrations and to validate the trends.

SAMPLING LOCATION AND POINT

Sampling location and point mean the general position within a waterbody and the exact position at a sampling location at which samples are obtained. The objectives of a programme sometimes immediately define the sampling locations. For example, when the concern is to measure the efficiency of a chemical plant for purifying water, sampling locations will be required before and after the plant. Similarly, when the effect of an effluent discharge on the water-quality of a receiving river is of interest, samples will be required from locations upstream and downstream of the discharge. For larger scale water bodies (e.g. a river basin. a large estuary, a large urban drinking water distribution system), however, the objectives may be defined in terms that provide essentially no indication of sampling locations. For example, objectives such as to measure river quality within a river basin or to measure the quality of water in a distribution system' give no indication of which of the virtually number of possible sampling locations are of interest. Such broadly expressed objectives are completely inadequate as a basis for the detailed planning of efficient programmes of sampling, and should always be sharpened so that they do indicate the position of sampling locations. A commonly useful device for helping in this respect is to consider the intended use of the water since this will aid in indicating these positions in a water body where quality is of key importance.

Figure-1 illustrates the location of river sampling sites alongwith the criteria for the choice of the different sites. Figure-2 and 3 illustrates similarly the location of sampling sites for lakes and underground water with corresponding criteria.

DEFINING THE DETERMINANTS OF INTEREST

The particular determinants appropriate to a programme are critically dependent on the type of water and the objectives of the study. Depending on the intended use of a receiving water, the parameters listed in table 1 are of significance for water quality characterization. These serves as guidelines for analysis of waste water quality for purpose of treatment and control. The parameters listed in table 2 are frequently used for the identification of various types of pollution associated with industrial waste water.

Some of the most important and most frequently used tests in the analysis of water are the non-specific tests listed in Table-3. These tests often measure a properly of a group of substances. For example alkalinity indicates the capacity of water neutralize hydrogen ions. Many of these tests are used to determine the suitability of natural waters for industrial or municipal use and to determine the type and degree of treatment required. Table-4 lists some of the more frequently measured parameters in pollution studies.

FREQUENCY AND TIME OF SAMPLING

The quality of water in various water bodies is rarely if ever constant in time but is subject to change. While there may be some relationship between the role of change of different variables others alter independently. In measuring the mean, maximum and minimum values of variables over a period of time the closeness of the monitored values to the true values will depend upon the variability of the variables and the number of samples taken. The larger the number of samples from which the mean is derived the narrower will be the limits of the probable difference between the observed and true means. These confidence limits are not directly proportional to the number of samples but to the square of the number. In order to double the reliability of a mean value the number of samples must be increased four fold.

Variations in water quality are caused by changes (increase or decrease) in the quantity of any of the inputs to a water body system. Such changes may be natural or man-made and either cyclic or random. Water quality variation may therefore be similarly cyclic or random. Since it is possible for some changes to occur in combination the reasons behind variations may some time be observed.

The underground waters. It is most pronounced in rivers and the ranges will be greater the nearer the sampling point is to the source or sources of variability. As the distance from the source increases longitudinal mixing smooths out irregularities and fewer samples are needed to meet given confidence limits. However, as the the distance between the source of variability and the sampling point increases not only will there be reduction in the range of variation but there will also be dilution and some variables will be reduced by self purification, deposition and adsorption. These effects must be considered if a sampling station used for quality control purposes is located some distance from the area of point of use.

In lakes the mass of water and good lateral mixing provide and inertia against any rapid changes resulting from modifications in inputs and outputs. Many lakes exhibit marked seasonal variations due to thermal stratification, overturn and biological activity. Depending upon the type of lake the sampling may be carried out with a seasonal bias related to the natural cycles of the lake.

Underground water has a lower variability than that of either rivers or lakes. The rate of quality changes depends upon the depth of sampling, the size and porosity, i.e. the water volume of the aquifer and the hydraulic conductivity. The time elapsing between changes in land use and in surface recharge water and their effect upon the underground water will depend upon the time of percolation. Variations are often, but not invariably, seasonal with a time lag according to the rate of percolation. Direct injection into boreholes or saline intrusion from subterranean sources may take effect more rapidly.

The time of sampling is also of main concern when the quality of the water shows more or less regular variations, e.g. diurnal varations in the concentration of dissolved oxygen in revers and variations of quality on start-up and shut-down of industrial plant.

It is seldom if ever that the quality of a water at only one instant of time is of interest. Normally, information is required for a time period during which quality may vary. The basic problem arises, therefore, of deciding the times at which to collect samples so that they will adequately represent the quality during the period of interest.

The best technical solution to this problem would often be to use an automatic, on-line instrument providing continuous analysis of the water of interest. This approach can be of great value in that, in principle, a continuous record of quality is obtained and the problems of selecting particular times for sampling does not arise.

Rivers

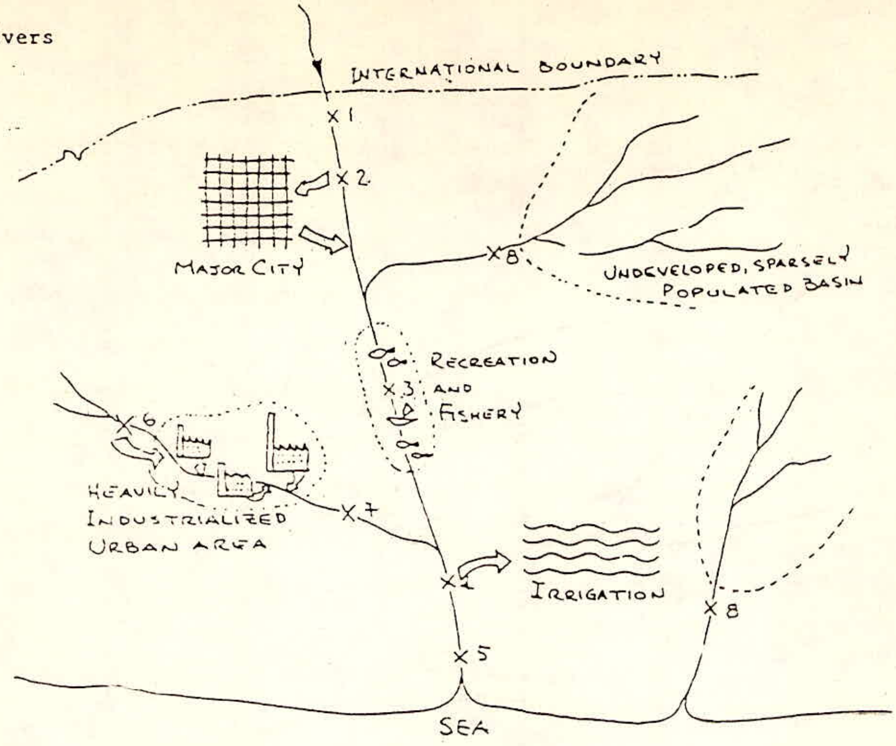


Fig.1 Monitoring site selection - Rivers

Station	Type	Criteria
1	impact (or baseline)	immediately downstream of an international boundary
2	impact	abstraction for public supply of large town
3	impact	important fishing, recreation and amenity zone
4	impact	abstraction for large-scale agricultural irrigation
5	trend	fresh water tidal limit of major river
6	impact	abstraction for large industrial supply
7	impact	downstream of industrial effluent discharges and important tributary influencing main river
8.	baseline	station where water is in a natural state (no direct or indirect pollution; no water use)

Lakes

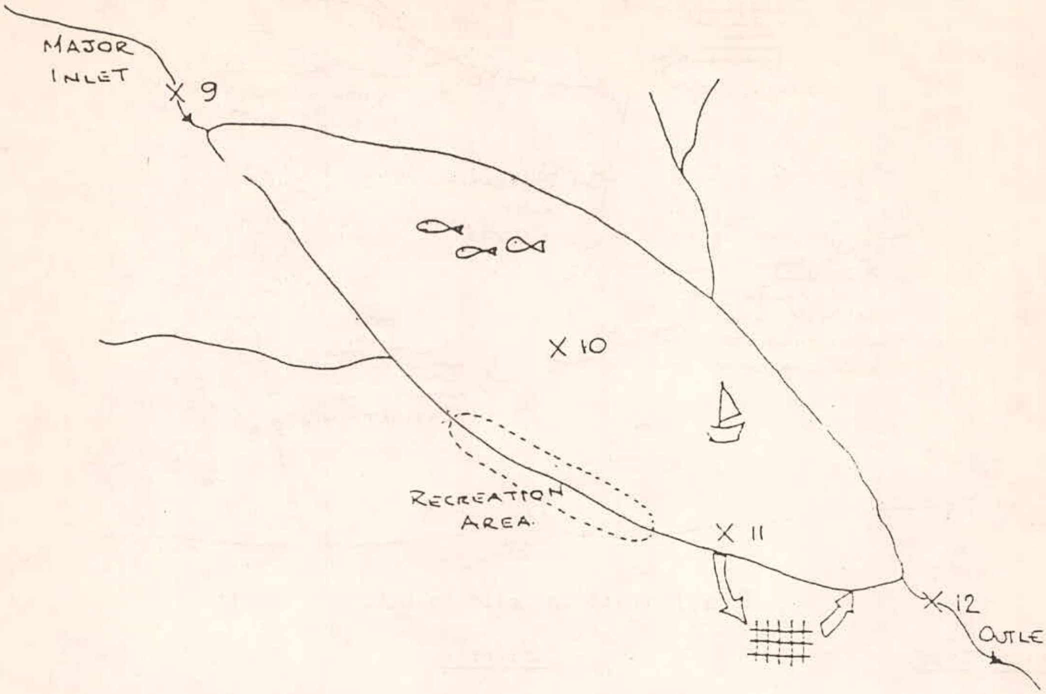


Fig. 2 Monitoring site selection - Lakes

Station	Type	Criteria
9	impact (or baseline)	principal feeder tributary
10	impact (or baseline)	general water quality of lake
11	impact	water supply of major city
12	impact (or baseline)	water leaving lake

Underground water

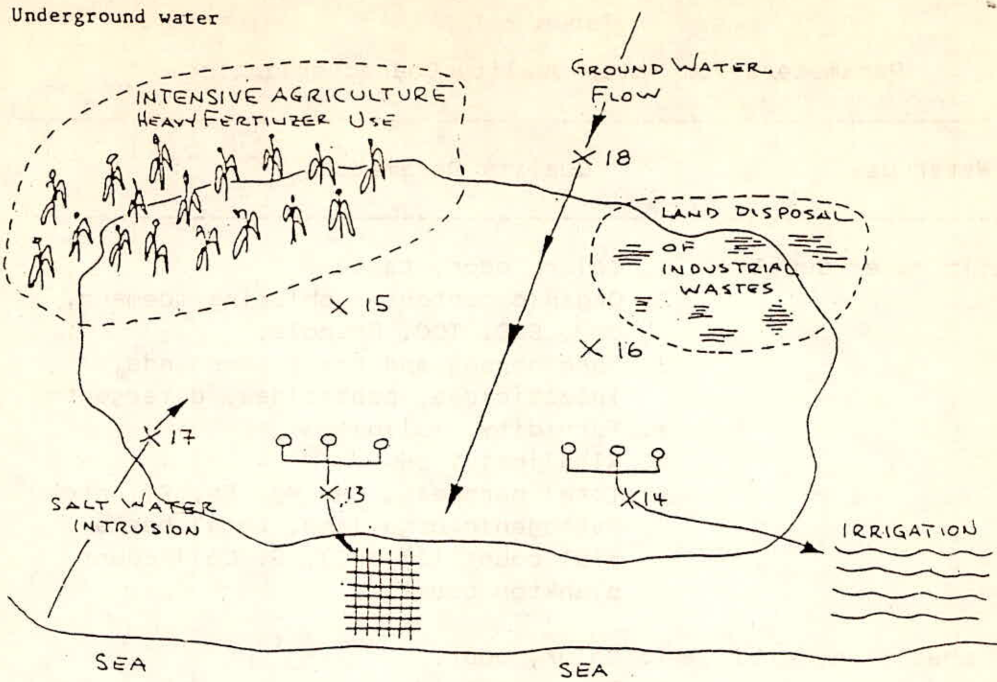


Fig.3 Monitoring site selection - Underground water

Station	Type	Criteria
13	impact	water supply to large town threatened by fertiliser residues and saline intrusion
14	impact	water for large scale irrigation threatened by leachate from waste tips
15 16 17	impact	boreholes for advanced impact monitoring
18	baseline	no human activities in the groundwater recharge area

Table - 1

Parameters for Water Quality Characterization

Water Use	Quality Parameters
Domestic Water Supply	1. Color, odor, taste. 2. Organic content; chlorine demand, COD, BOD, TOC, Phenols. 3. Carcinogens and toxic compounds, insecticides, pesticides, detergents 4. Turbidity, salinity 5. Alkalinity, pH 6. Total hardness, Ca, Mg, Fe, Si, etc. 7. Pathogenic organisms, total bacterial count (37 o C), E. Coli count plankton count.
Fish, shellfish, wild life, and recreation	1. Color, odor. 2. Toxic compunds 3. Turbidity, floating matter, sludge deposits, salinity. 4. Temperature. 5. Dissolved oxygen, BOD 6. Alkalinity, pH. 7. Pathogenic organisms, plankton count 8. Nitrogen, phosphorus, etc. (inorganic nutrients which support algae blooms and other undesirable aquatic growth.
Agricultural Irrigation	1. salinity and Na-Ca content. 2. Alkalinity, pH. 3. Pesticides, growth regulators, etc. 4. Persistent synthetic chemicals (e.g. polyethylene derivatives, asphalt sprays, etc.). 5. Pathogenic organisms.
Watering of Livestock	1. Salinity 2. Toxic compounds 3. Pathogenic organisms 4. Plankton count

Table - 2

Significance of parametric Measurements

Test or Determination	Significance
Dissolved solids	Soluble salts may affect aquatic life or future use of water for domestic or agricultural purposes.
Ammonia, nitrites, nitrates, and total organic nitrogen	Degree of stabilization (oxidation) or organic nitrogenous matter.
Metals	Toxic pollution
Cyanide	Toxic Pollution
Phenols	Toxic pollution, odor, taste.
Sulfides	Toxic pollution, odor.
Sulfates	May affect corrosion of concrete; possible biochemical reduction to sulfides.
Calcium and magnesium	Hardness
Synthetic detergents	Toxic pollution

Table-3

Nonspecific Water Quality Parameters

Physical Parameters	Chemical Parameters	Physiological Parameters
Filterable residues	Hardness	Taste
Salinity	Alkalinity and acidity	Odor
Density	Biochemical Oxygen demand (BOD)	Color
Electrical conductance	Chemical oxygen demand (COD)	Suspended matter
	Total carbon	Turbidity
	Chlorine demand	

Table-4

Tests used for the Measurement of Pollution of Natural Waters

Nutrient Demand	Specific Nutrients	Nuisances	Toxicity
Dissolved oxygen	Nitrogen:	Sulphite	Cyanide
Biochemical Oxygen demand	Ammonia	Sulphite	Heavy metals
Chemical oxygen demand	Nitrate	Grease and oil	Pesticides
Total carbon	Nitrite	Detergents	
	Organic nitrogen	Phenols	
	Phosphorus:		
	Orthophosphate		
	Polyphosphate		
	Organic phosphorus		

INTRODUTION

General

Due to acute crisis of energy and depleting raw material resources, the development plans are taking up a major step forward. As a consequence of this the environmental concern has also got a big boost. There is a day to day tussle between the environment protectors and the people responsible for future development. However, several studies by sober environmentalists have shown that development and protection are not only compatible but can also be mutually reinforcing. These studies have reduced the fears to some extent, but the motto is still not "Development without Destruction".

Sustainable development and environmental protection are two mutually related aspects for an optimized management of resources. There should nothing be against taking up large water resources projects for generation or energy of for the purpose of irrigation but before such a multi-dimensional scheme is taken up a thorough analysis of the effect of the project on the environment must be made. This would give the designer many ideas by which the design of the projects could be greatly altered so that the negative effects of the project on the environment are minimized, without much affecting the cost criteria.

Because of the uneven distribution of rainfall in space and time, steep slopes of rivers and water pollution problems in the midstream and downstream segments of water course, water resources development e.g. building of dams, reservoirs etc. are essential for industrialization and economic growth of India. However, as mentioned above, this development can also induce significant impacts on the environment. Water is needed to achieve water needs, but one has also to worry about the adverse effects on the environment. Hence the environmental impact assessment (EIA) has two important roles to play, one is to assist the engineer and policy makers to choose a proper alternative and another is to decrease environmental impact due to such development. Because, EIA is till a relatively new concept in India, the ability to evaluate environmental impact has not kept pace with the ability of engineering part of water resources development projects (WRDP). Thus there are many difficulties in establishing a sound and generally acceptable EIA system for impact evaluation of WRDP. However, before any such procedure is used, it would be necessary and informative to list out some important definitions (UNESCO, 1984).

Definitions

The most commonly used definitions in this report anu relevant literature are given below.

ENVIRONMENTAL SYSTEM

The creation of the circumstances of life for human beings or society by the surrounding objects, region and conditions can be described by a system referred to as environmental system. This system is composed of various components including physical, chemical, biological and/or man made nature. The complete knowledge of an environment system is still under investigation and can not be described completely at this stage.

INDICATORS

In order to describe the components of an environment system in quantitative form certain measurements or observations are necessary which can be formed as indicators of the environmental system. Thus, the status of various components of environmental system can be described quantitatively or qualitatively by indicators.

STANDARDS

The values of indicators of various components of the environmental system should be upto certain limits within which the occurrence of the selected component should lie so as not to be detrimental to man or his environment. Based on the ideal conditions of living. The values of standard may be selected to which indicators are compared to know the status of environmental system.

INDEX

In order to find the status of various components of environment or the environmental system, it may be possible to define an index which relates to observed value of indicator to the standard, both corresponding to the component in respect of which the environmental status is to be assessed.

Need for Environmental Indices

Development of water resources has been practiced since the dawn of civilizations for varied purposes including drinking water, irrigation, extraction of energy, transportation of goods and carrying away of wastes. While these projects have on one hand provided for a number of beneficial purposes, there have also been incidents when these have led to certain undesirable effects on the various social, biological, physical and chemical components of the environment. The adverse impacts may perhaps be due to inadequate assessment during planning and decision making stages of these projects. In order to have proper development of the resources to meet basic human needs without destroying the ecological basis on which the sustainable development depends, an environmentally sound management approach is required. For this purpose, some hydro-environmental indices for the evaluation of water projects may need to be defined. These could be used for environmental impact assessment studies of these projects which are necessary because of non-uniform distribution of rainfall over space and time, steep slopes in rivers and pollution of water downstream segments of many rivers and pollution of water downstream segments of many rivers. The methods for evaluating a water project and all its potential impacts are still largely in the development stage. The problems of analysis, interpretation, and presentation are immensely complex when a project must be evaluated for several objectives and numerous impacts. The evaluation processes may include consideration of items like national economic development, environmental quality, regional development and social impact etc. (Bhatia, 1983 and 1986).

The environmental impact assessment (EIA) is a relatively new concept in India and the techniques of EIA have not been developed independently whereas, the engineering aspects of the planning, executing, construction and operating of water projects are very well advanced. The environmental assessment should generally address all the quantitative and qualitative changes which would result from a water project, and to these identified changes some values must be assigned. These values need to be compared with the standard values corresponding to the identified changes for achieving overall goals of the society. In other words, there is need to develop indices corresponding to each component of the environment which will provide comparative information to aid in the evaluation and selection among project alternatives to meet a particular water related need. The present report discusses the basic philosophy of development of hydro-environmental indices, their types and use in EIA study of water projects.

WATER RESOURCES DEVELOPMENT AND ITS IMPACTS

Types of Water Resources Projects

Generally water resources projects are classified based on their intended functions and purpose. However, for assessing the environmental impacts of the projects these may be classified as per the physical nature of the projects. Basically there are five broad categories of water projects (Ha[illegible]er, 1979; UNESCO, 1984) as below.

i) Impoundment of water
  a) reservoirs
  b) artificial control of lake outflows
ii) Channelization
  a) irrigation canals
  b) navigation canals
  c) drainage works
  d) dykes for flood protection
  e) erosion control measures
iii) Diversion of Water
  a) between natural basins
  b) for consumptive use in home or industry
iv) Waste dilution and assimilation
v) Ground water extraction and recharge
vi) Vegetation management for increased water yield.

The last category of water project is of recent origin and is still under experimentation stage. The basic principle on which such a project is designed is that of manipulating the vegetation in upland watersheds, the yield of water for downstream users can be increased and this increase in yield is attributed to variation in evapotranspiration losses associated with manipulation of vegetation or change in land use. As the evaporation/evapotransipiration process accounts for significant portion of the annual precipitation input on must watersheds, the potential of increasing water yield by vegetation manipulation becomes quite attractive.

The water projects may consist of several components which fall into several of above given classifications. However, for environmental impact assessment, developing indices, fixing standards and indicators, a clear understanding of the nature of each component in the project is required.

Hydropower Development and Its Envirornmental Impacts

There has been considerable development in hydropower production owing to increasing requirements of growing population and the quality of life. This section focuses the discussion on all the main environmental aspects of water projects. Since there are always gaps between recognition of a problem, finding solutions and implementing relevant measures, this part concentrates on the status of each aspect rather than on the details of the problem. Other than the effects as caused by irrigation projects on environment, additional effects may also be there due to hydropower projects because of their relatively large dimension (Goodland, 1985). To present a comprehensive picture and to make the report readable as a interdisciplinary information source the various impacts are being presented here under.

(a) HEALTH

It is recognized from olden times that water resources development projects can adversely affect the habitats around the project area and downstream of the project. However, it has been recognized recently that these adverse effects can be greatly minimized if due care is taken during the planning, design, construction and operation of Project. Malaria is a glaring example of the case in point. Nowadays, material vector control by destruction of habitat, encouragement of mosquito larvae eating fish, transmission reduction (nets), prophylaxis and chemotherapy, together with some larviciding and adulticiding is well known and our country is a leader in malaria control. However, there are certain disease vectors which can be controlled at the initial stages only and if preventive measures are not taken at appropriate time such vectors are impossible to eradicate. This again stresses the need for taking precaution at the time of design of the project. As an example Schistosomiasis is such a vector which can be kept out of a new water project if careful preventive measure are implemented, but the snail once arrived is almost impossible to eliminate (Maudgal, 1985).

(b) RESETTLEMENT

The resettlement of people is expensive and time consuming when done acceptably. The cost of rehabilitating the people as a cost of the water project has been taken seriously only recently and the record is improving. The people can and should be better off after the project is completed. All resettlement costs such as employment creation purchase of compensatory house lots, and agriculture lands are to be fully internalized in the project analysis. The situation is not easy as the number of persons displaced is large, their cultures differ greatly from main stream society and compensatory land is not readily available. The hydro projects should become regional development activity which integrates rural development for people. Resettlement of vulnerable ethnic, unacculturated minority should be avoided and if unavoidable special precaution should be taken (Mistry & Purohit, 1985).

(c) WILD LIFE

This is receiving greater importance nowadays as this impact falls into the irreversible category of environmental effects. The main losses could be of wild lands, wild life, extinct species etc. Extinction should be minimized by proper sitting. Loss of wild life can be mitigated by including or wild land management equivalent to the inundated tract unit in the watershed. It would be advisible to undertake a biotic inventory of the tract to be flooded in order to identify rare or endangered species and to scope out the magnitude of wild life resources. Measures can thus be incorporated for wild life salvage or rescue or their transfer to protect areas (Dinesh Mohan, 1986).

(d) FISHERIES

Most fish do not migrate and hence a dam does not impede them. However, mitigation if any will be impaired without passage facilities if a dam is constructed as an obstruction. The main measure seems to be the development of fishery potential within the new reservoir. With due attention reservoirs can and should become significant sources of protein, employment and economic profit. Realization of the full fish potential of impoundments is not yet achieved in projects and more attention is warranted in this regard. Here it would be appropriate to stress the importance of estuaries in this regard. The anormous biological productivity and importance of estuaries is becoming quantified, but much remains to be done in order to conserve their values.

(e) BIOMASS REMOVAL

This relates to removal of biomass which is needed downstream for fisheries and navigation. Valuable timbers and fuel should be salvaged. Opportunity cost of lost timber and foregone use of inundated land should be internalized.

(f) WATER QUALITY

The construction of a water resources project affects the water quality within the reservoir and in the downstream. The effects of such constructions may be clearly visible in typical structures with salinity intrusion loss of flushing, decrease in nutrients etc.

(g) EROSION

Erosion in the upstream will lead to sedimentation which in turn will affect the dead in the beginning, and live storage at later stages. This particular impact could be countered by adopting to judicious watershed management practices. However, below the dam, the erosivity definitively increases.

(h) WATER WEEDS

The growth of weeds can increase disease vectors and transpiration also increases which in turn is responsible for water loss, adversely affecting the water quality and fish culture. The increase in weed growth clogs the navigation channels and affects irrigation and recreation. However, the weeds can be put to considerable usage. Suffice to say that the problems of weed growth are well recognized. Solution exist to convert weeds into resources (Lohani, 1982)

(i) ARCHEOLOGICAL SITES

In a country like ours where lot of importance is given to religious values, this is a very important aspect to be considered. Only recently has the relationship between water projects and loss of cultural property been great enough to call for action, however. It is proper to conduct a reconnaissance survey of the prospective reservoir area before construction of a dam is taken up. If important cultural property is found, the project should be relocated or else stayed, while archaeological measures are conducted.

(j) NAVIGATION

This may need special provisions such as docks, cleared shipping lanes etc. In some cases lake transport may become economically advantageous. However, construction of water resources project definitely points to a relook at the navigation system.

An excellent presentation of possible consequences of a multi purposes dam and reservoir project are presented by Carpenter (1985) as given in figure 1.

Irrigation Development and Its Environmental Impact

For the last several decades major stress has been directed towards exponential growth of irrigation. Sub consciously or consciously mankind has always been concerned about the impact of irrigation development on the environment. However, for the last one and a half decade the environmental concern has been a major issue in our country also. The plausible reasons could be advances made in the environmental sciences, rapidly changing technology and agriculture in general and irrigation in particular, and the most important being the phenomenal growth in the demand of agricultural products.

The effects of irrigation development are mostly confined to the project sites while in some cases the effects are concernsly spread on the other endeavors and the life outside the project. In some rare cases the effects may be spread across the international boundaries also. It is conceivable that difficulties and mishandling of impacts having a wider dimension requiring policy decisions at national and international levels have been allowed to hinder progress in developmental efforts. Such impacts are very vital and have to be tackled at the appropriate levels by suitable remedial measures. For example, at the project level, issues like soil degradation, primary health, social issues etc. would be relevant whereas at wider levels water quality, hydrological impacts, regional droughts etc. may be relevant and at global level protection of wild life, conservation of forest, long range economic impacts etc. could be the pertinent issues to be considered (Framji, 1986).

The concern about environment with the development of irrigation can be broadly addressed to :

a. Water pollution

b. land degradation and

c. ecosystem imbalance

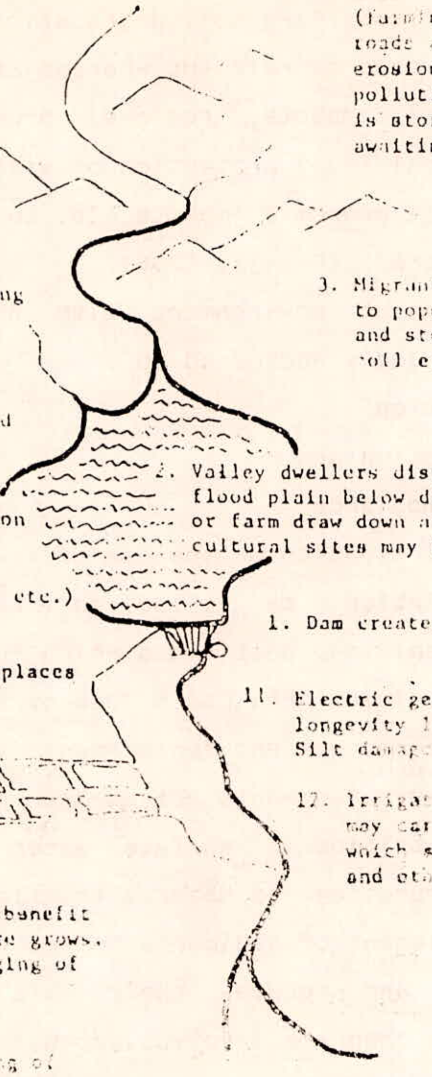
Over or under irrigation or the use of low quality water may result into pollution by dissolved solids, sediments, mal-nutrients, organic and pesticides which in turn may affect the environment. Sediment inflicts a loss of top soil which is almost impossible to recover and replacement value involves hug sum of national money. Sediments act as transporting vehicle of pesticides and malnutrition in surface water and aquifers and cause toxic and/or carcinogenic hazards to fish, wild life and human health. Settlement of sediments in reservoirs affects the reservoir capacity and reduces their life. The influx of sediments into river channels involves expensive dredging Leaching of pollutants into ground water results into complex reactions and is currently not understood and is one of the premier areas of research in irrigation water use.

The construction and operation of irrigation systems also presents several environmental concerns:

a) destruction of river and adjacent territorial habitat

b) destruction of productive form and forest land by

Figure 1. Some Possible Consequences of a Multipurpose Dam and Reservoir Project.



1. Dam creates multipurpose reservoir.

2. Valley dwellers displaced to uplands or to flood plain below dam or begin fishery in lake or farm draw down area. Wildlife habitat and cultural sites may be inundated.

3. Migrants from reservoir site add to population pressure on marginal and steep sloping lands causing soil erosion.

4. Existing upland activities (farming, forestry, agroforestry, roads and settlements) cause soil erosion, silt and chemical pollution of streams. Sediment is stored in delivery system awaiting storm events.

5. Sediment from eroded soil is deposited in headwaters of lake at first causing flooding of adjacent land.

6. Turbidity increases in lake interferring with fishery and recreation.

7. Nutrients cause eutrophication and aquatic weed problem (lowered dissolved oxygen, fouling of equipment, odors, etc.)

8. Eventual sedimentation displaces active storage capacity.

9. Irrigation water is primary benefit and dependence of agriculture grows. Silt in water requires dredging of feeder canals.

10. Salinization and waterlogging of soils may occur from improper control of irrigation.

11. Electric generating capacity and longevity lost through sedimentation. Silt damage to turbines increases O & M.

12. Irrigation return flow to river may carry toxic chemicals and salts which affect downstream fisheries and other water uses.

13. Severe storms require water release and flood plain damage.

14. Many dependencies develop on a water management system which may be rather short-lived.

reservoir inundation

c) raising of water table

d) water logging and salt accretion

e) detrimental effects of storage and diversion projects on water quality

f) loss of recreational amenities

Maudgal (1985) has given a schematic representation showing the various environmental aspects (Figure 2) of irrigation projects.

In summary, it can be inferred that at current stage of knowledge of the state of environment it may be appropriate to say that environmental issues relating to irrigation development projects are quite evident in gross terms i.e. as cause and effect. However, it is not always simple and feasible to identity and quantify intermediate controllable parameters for the designer to cater for future environmental changes. This again stresses the need for taking up immediate research considering actual irrigation projects and their impact on the environment. The evaluation of environmental hazards and the cost involved in their alleviation will enable identification of those aspects of irrigation which are in the greatest need of amelioration. Increasing the efficiency of water use and scientific allocation and conveyance of existing developed water supplies irrigation network systems will ensure, as far as can be foreseen, the widest extent of environmental benefits. Scientific management of irrigation is thus now an absolute essential.

ENVIRONMENTAL IMPACT ASSESSMENT AND TECHNIQUES

General

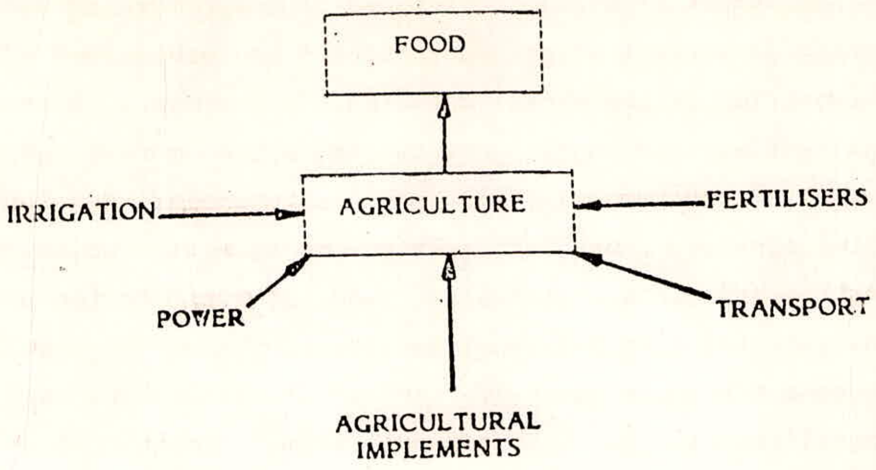
Any national policy for environment protection aims at encouraging a productive harmony between man and his environment such that while essential developmental activity is not stopped and lasting damage to the biosphere is prevented. The purpose of an Environmental Impact Assessment (EIA) is to determine before implementation the environmental effects of a proposed action. It defines and assesses a proposed action's physical, biological and socio-economic effects, bringing together all aspects of a project in a form that permits a decision to be made logically and rationally. Negative environmental impacts are exposed, thus allowing their alleviation through the identification of possible site and construction/process alternative.

In many countries, the EIA has been incorporated in legislation. The Indian Policy regarding the environment has been enunciated in the approach to the Seventh Plan (1985-90) as follows:

"All future development programmers must take environmental considerations fully into account. Towards this end, environmental factors and ecological imperatives will have to be incorporated into the design of all developmental projects from the very commencement of planning. All activities which might cause loss of environmental quality or unacceptable damage to ecosystems will have to be carefully regulated. Planning and implementation of projects should minimize environmental degradation such as the loss of genetic diversity, air and water pollution and other environmental hazards which might threaten health and well being. Environmental planning must how be projected to achieve both sustainable development as well as to ensure quality of life".

Rees (1981) has suggested to include following details in an impact assessment:

- a description of the nature and characteristics of the proposed development;
- a description of the existing bio-physical and



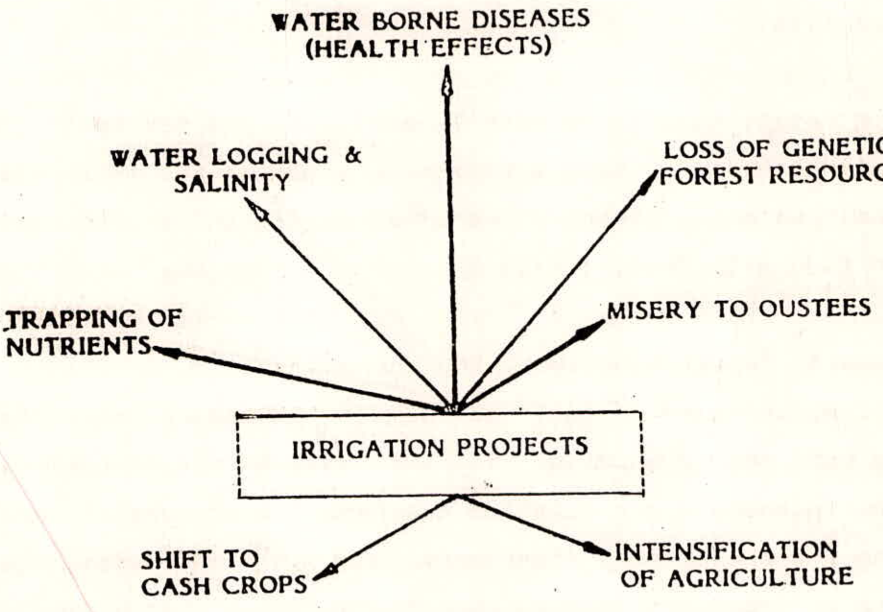


Fig. 2 Related Environmental Aspects

socio-economic environment;

- an assessment of significant types of environmental impacts during site preparation, construction and operation;
- integration of the expected bio-physical impact with the indirect socio-economic consequences and community response;
- review of the compatibility of the proposed development with approved land and water management objectives, and environmental standards and quality criteria for the area(s) likely to be impacted;
- reasons for choosing the particular location and project specification and operation from among possible alternative, adverse impacts which can not be avoided; and
- a summary suitable for decision makers and other interested parties;

In order to have above details available and for their proper analysis multi-disciplinary approach is a must. The main aspects to be dealt with the personnel required for such a job are as shown in figure 3 (Rees, 1981).

Environmental Impact Assessment Procedure

A comprehensive impact assessment procedure may involve carrying out the evaluation in two stages i.e., preliminary assessment procedure and detailed assessment procedure. The idea of having the preliminary assessment is to have an early judgement of severe or important impacts upon the existing environment. The preliminary assessment will be based on the initially available data such as maps, reports, photographs, plans, siting & operation alternatives of the project and competence of the staff available. By systematically relating the characteristics of the proposed development to the site choosen and its surroundings, an information matrix can be developed which will contain the

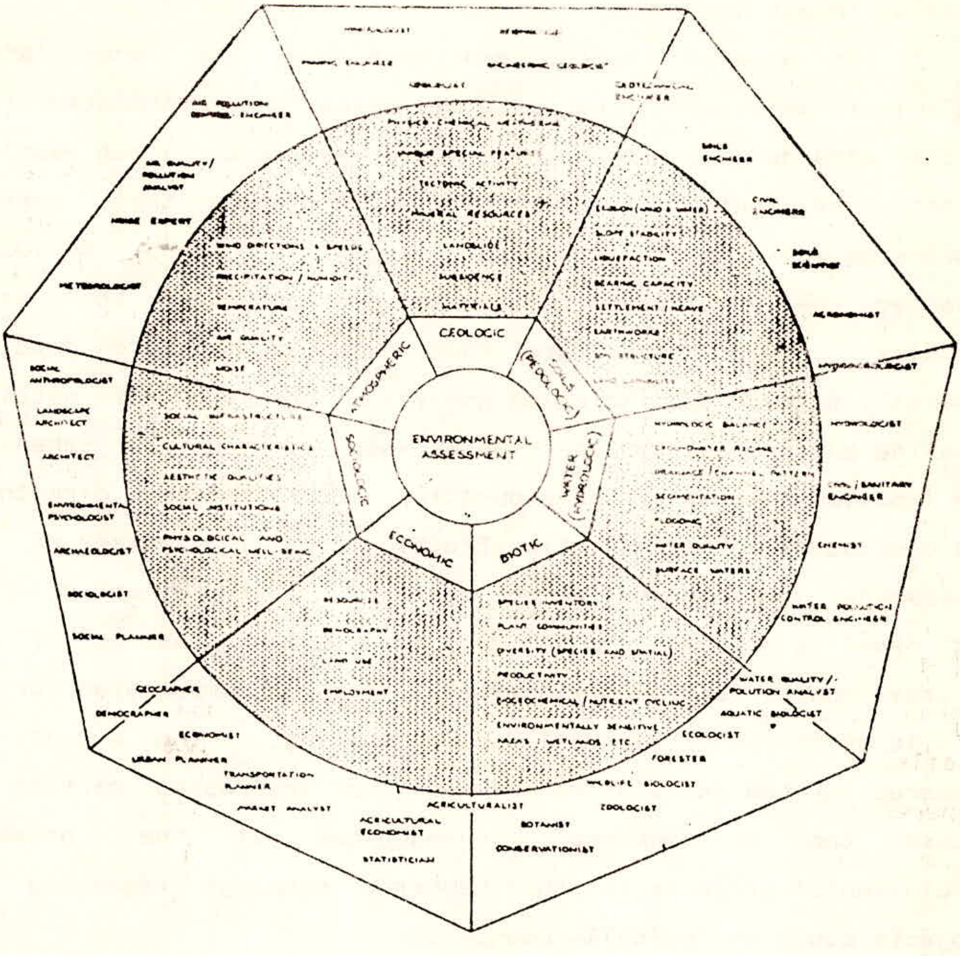


Figure 3. Major components and subcomponents of environmental impact assessment and relevant specialists.

characteristics of the proposed development in columns and characteristics of the site and its environs in rows. Based on such matrix the critical components of environment which are likely to be affected severely can be identified. Such identification will indicate whether there is any need for detailed impact assessment.

If no adverse impacts are confirmed, or when after preliminary assessment the problem sites are eliminated from further consideration, then there is no need to carry out detailed impact assessment. In case it is confirmed that certain components of the environmental system is being seriously affected, the particular components are subjected to greater scrutiny. The impacts are then examined in more details, generally through the increased analytical precision of detailed baseline and process studies. More expert opinions are taken on the impacts in terms of their duration, reversibility, directness and cumulative and synergistic effects. Finally a summary of the assessment is prepared which contains determination of the cost/benefits of the proposed project, an explanation of how adverse impacts have been minimized, offset or compensated for and details of follow up surveillance/monitoring. The summary is prepared for the decision makers and other interested parties to expose the environmental consequences of the proposed developmental projects so that adverse campaign regarding the projects could be logically countered.

While assessing the impacts of proposed development it is required to know the nature and characteristics of the proposed development. Sufficient details should be available to give a clear picture in respect of the following aspects of the proposed projects as included in the feasibility report:

- general location, specific siting and project layout
- size/magnitude of operation

- site preparation and construction
- transportation/communications requirement
- accidents/hazards
- waste disposal and control
- monitoring and surveillance systems

Also, before attempting to analyze the effects on environmental system as caused by proposed development, it may be worthwhile to assess the nature and characteristics of the existing environment. For this matter the existing environment will need to be described in terms of its present characteristics, especially the ones which are likely to prevail for the entire duration of the proposed development. Such evaluation of existing environmental system may require initiation of large scale surveys and /or long term monitoring programmes, and therefore, needs sufficient time for completion. The effects on environmental system may be evaluated by having known the effects on various element which may consist of the following:

PHYSICAL AND BIOLOGICAL RESOURCES

1. Climate
2. Water
3. Geology
4. Soils
5. Noise and Vibration
6. Ecology
7. Environmentally sensitive areas

HUMAN AND ECONOMIC DEVELOPMENT

1. Water supply
2. Flood Control
3. Navigation
4. Transportation

5. Land use and capability
6. Fisheries/wild life management

QUALITY OF LIFE VALUES

1. Socio and economics
2. Resettlement
3. Public health
4. Nutrition/diet
5. Recreations and aesthetics
6. Archaeological, historic and cultural sites

Once the existing conditions of the environmental system are ascertained in terms of above listed elements, then attempts are made to outline impacts of the project on all or some of these elements as a result of likely utilization, alteration and impairement of natural resources affected by the project. Some typical examples in case of water projects which need to be seen are as given below.

(A) Physical and Biological Resources

Climate

It may be worthwhile to check whether the micro-climate is being affected as a result of project implementation e.g. changes in meteorological phenomena.

Water

The hydrologic regime of streams or river systems may get modified along with changes in water quality. Similarly, the ground water quality and quantity in the vicinity of reservoir, changes in water tables conditions mays take place. the rate of erosion and sedimentation may get increased which may reduce the life of reservoir along with deteriorating water quality. The yield of water may get influenced

Geology

The geological aspects like effects on tectonic/seismic activity; mineral resources, physical and chemical weathering; land slides and subsidence characteristics are potential impact assessment issues.

Soils

The related matters on which the project development may have impacts as far as soils are concerned may include erosion of soils from watershed, slope stability, bearing capacity and soil structure.

Ecology

The effects on flora and faunas resources of watershed is another vital issue to be investigated for impacts of development projects. The fauna and flora resources in the inundated area and their regeneration and rehabilitation aspects need careful investigation. Other major effects may include anticipated physical, chemical and biological characteristics of the reservoir, nutrient trapping in the reservoir, effects on marine/estuaries zones, changes in fish population due to possible change in quantity and quality of flow and expected conditions of fisheries in reservoir and in the altered downstream zone(s), and potential for growth of water weeds in the reservoir.

(B) Human and Economic Development

Water Supply

The effects of proposed development on quantity and quality of water available for downstream users.

Flood control

The likely impacts due to flood control including potential reduction in flood damage and reclamation of lands for agricultural use are to be considered.

Navigation

Likely effects of the project on navigation above and below the project and augmentation of other facilities such as transhipment and landing facilities.

Transportation

The effect due to likely requirement of transportation as a result of proposed development and alterations in highway and railroad routes are needed to be considered.

Land use and Capability

The impacts on land use pattern and land capability types after proposed development is needed considered.

Agriculture

The improvement in agriculture due to augmentation of downstream flow needs to be assessed.

(C) Standard of Living

The effects of development on the living standard of the people affected by the project mays be required. This may be in the form of finding how the newly constructed roads, industries coming up after development, electrification etc. affected the life of people. The assessment should also include effects as caused by conditions after resettlement of population, changes in agriculture practices. The chances of having water borne diseases should be studied the effects of soda proposed sanitation facilities for the new habitation around the project should be studied. The recreation potential of the proposed development and plans for its effective development should be assessed. Similarly, the effects on archaeological, historic and cultural sites which will be inundated after development should be highlighted and schemes for preservation should be suggested.

Once the assessment report on various aspects is available it should be possible to say whether the proposed site is alright for development or alternative site needs to be chosen where relatively the impacts (the negative ones) will be less. After studying the assessment reports of all possible alternatives, the one causing acceptable environmental impacts should be the one chosen for development. Department of Environment has also formulated guidelines for this purpose (Maudgal, 1985). A step-wise procedure for preliminary and detailed assessment for a proposed development is shown in Figure 4.

Techniques of Environmental Impact Assessment

After a careful study of the beneficial effect and negative impacts of a WRDP, one can draw a significant conclusion that there is a great necessity of thoroughly analyzing the environmental impacts of WRPS before they are actually taken up for construction. An in depth study of the expected outcome may lead to many considerations which may significantly alter the design of WRPS but may also ensure environmental protection. Some of the methodologies which are being used in developed countries are:

AD HOC TECHNIQUES

This technique of EIA is quantitative by nature and gives information in comparative statement for different development schemes or for different options of sites for a WRP. This method is very simple and can be easily understood by decision makers as well as laymen (Raw and Wooten, 1980). It is not based on expert opinion and thus can be prepared quite fast. For example, it could give the extent of area submerged by a reservoir, if alternate sites are chosen or earth work to be done if two designs are adopted. Table 1 gives a hypothetical example to illustrate this method.

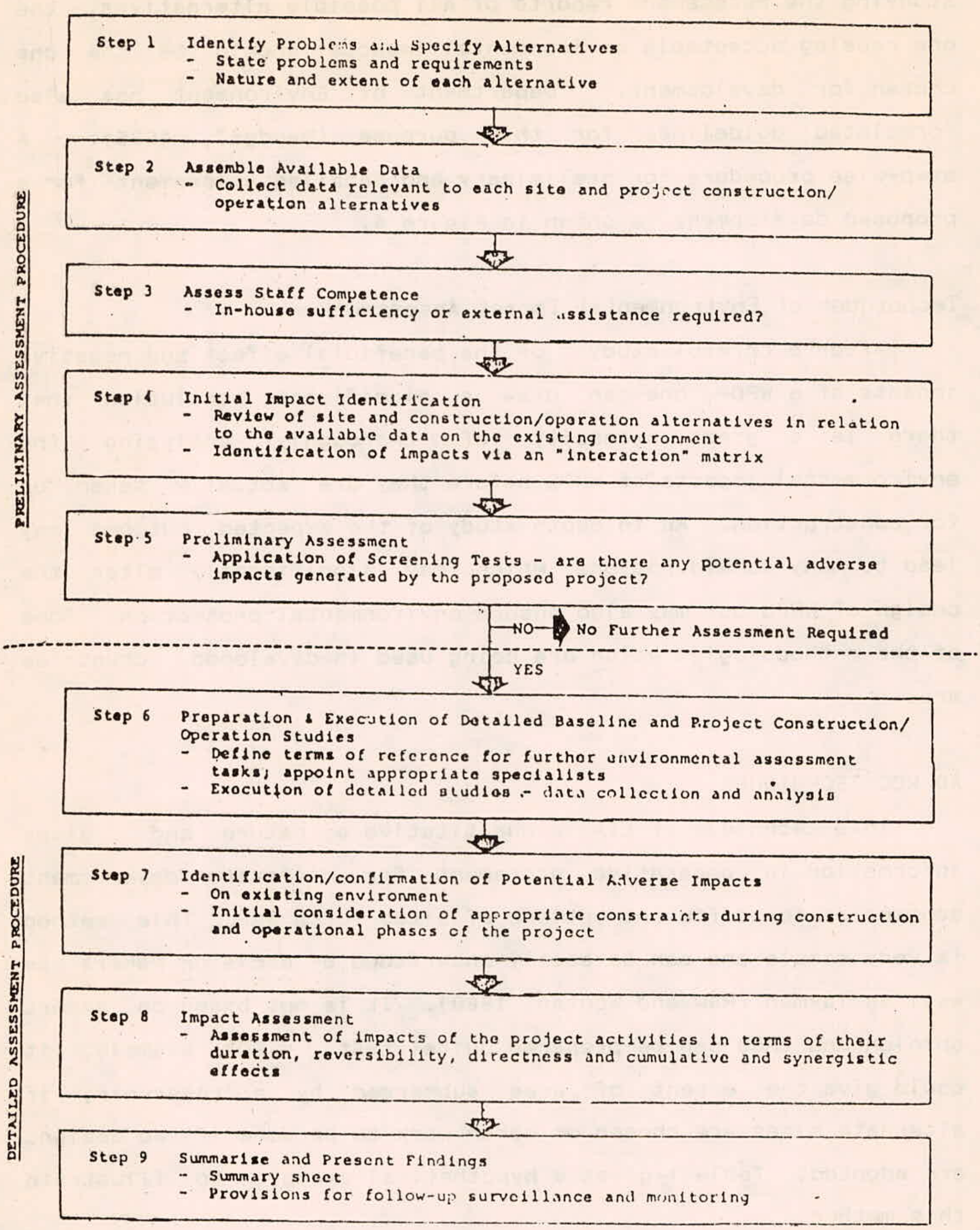


Figure 4. Preliminary and detailed assessment procedures for proposed developments.

TABLE 1: Example of Ad hoc Technique

Sr.No.	Item	Various		Alternative/sites		
		A	B	C	DE	
1.	Submerged Area	10000	2000	5000	1000	15000
2.	Irrigation potential	50000	10000	20000	5000	30000
3.	Power Generation	11000	10000	7000	3000	13000
4.	Soil Erosion	4a	2a	3a	a	5a
5.	Displacement	25000	15000	10000	5000	20000
6.	Weed Growth	Yes	No	Yes	No	Yes
7.	Fish Culture	No	Yes	Yes	Yes	No
8.	Water Quality	Yes	Yes	No	No	No

ENVIRONMENTAL INDICES

Index is a quantified limit of a specific environmental element. Quantification in this case can be a simple 'yes' or 'no'. Depending on the project, a certain number of a indices must be incorporated into the impact story. Indices can be divided as:

a. Resources indices: These types of indices show the change of the potential of the system or its subsystem.

b. Ecological indices: These types of indices show the change of abiotic and biotic environmental component.

c. Socio-economic indices & cultural indices.

These types of indices show the changes toward the improvement of living conditions.

The use of such indices can be seen in the Ad hoc method explained earlier. The indices can form the matrix column of the table. The identification, selection and classification of environmental indices is essential for a successful impact assessment (Singh, et.al., 1985) . Most EIA studies contain a list of indices ranging between 50 to 1000 with the majority having 50 to 100 indices (Canter, 1985). The number of indices would depend upon the length of data, size of data and the type of data. While developing or identifying indices for new WRP, the baseline data of an existing project in the vicinity may be very useful. However, the ad hoc method and indices method derive a lost from each other.

MATRIX ASSESSMENT

This method is based on the action-response relation and is expressed by matrix notation (Leopold et al., 1971). On the one side of the matrix, the characteristics of existing situation are displayed while on the other side, the environmental factors affected by construction and operation of the project are listed. Sometimes the construction effects may prove to be more damaging than the operational effects. Expected impacts are noted on the interaction points of the matrix and are focused for their importance. Table 2 gives an example of matrix methods. Whenever a detailed appraisal of certain aspects included in the initial matrix is needed, an ,expended matrix is developed (Clark et al., 1981, Pendse 1985; 1987).

CHECKLIST METHOD

This is another quantitative method which facilitates to rapidly assess the environmental impact. Checklist methodologies range from simple listing of environmental elements to sophisticated techniques where a weighing factor is assigned to each element according to its importance, and then sealing techniques evaluate the impact from each alternate, solution. A large number of checklist have been formulated. For water resources there are checklists of the Environmental Impact Center (1973) and of Battelle Columbus Laboratory (1974). A checklist of 62

TABLE 2: Matrices Method

Characteristics of existing situation	Characteristics of proposed development									
	1	2	3	4	5	6	7	8	9	...
1. Water quality										
2. Land use										
3. Climate										
4. Employment										
5. Water supply										
6. Displacement										
7. Health										
8. Flora & fauna										
9.-- --										
10.-- --										
11.-- --										

*Noise, 2. Pollution, 3. Dust, 4. Vibration, 5. Solid wastes, 6. Odors, 7. Water demand, 8. Employment, 9........, 10. ....

environmental factors related to environmental quality was developed by Canter and Hill (1979). A simple example of the check-list method is given in table 3.

NETWORK METHOD

The environmental components are dealing with human phenomena and hence are very complicated and complex. These represent the impact causes and consequences through an integrated network system. The network is generally shown as a tree which is sometimes known as impact tree. To arrive at the tree structure, one has to answer a series of questions related to reach of the project activity, such as activity, such as primary impact area, secondary impact areas, etc. The main limitation of the network approach is that this provides inadequate information on the technological treatment of the problem (US SCS, 1977).

TABLE : 3 Checklist Method

Item	Likely Impact					
	Beneficial			Harming		
	Short long	Reversible irreversible	Local wide	Short long	Significant normal	Local wide
1. Atmospheric						
a.Air pollution						
b.Climate						
c.Temperature						
2. Land use						
a. Forests						
b. Grazing						
c. Residential						
d. Industrial						
e. Agriculture						
3. Water						
a. Lakes						
b. Rivers						

OVERLAY METHOD

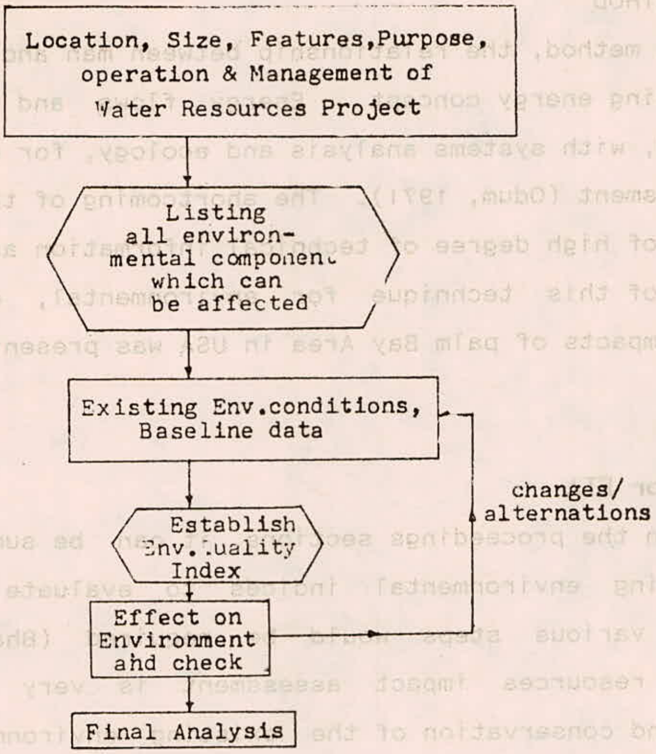
In this procedure, the assessment of environmental impact is done by using the cartographic techniques. Here,as the project area is depicted by physical, social, ecological characteristics of the environment. The maps are superimposed on each other to assess the environmental characteristics laying within the project boundary (Lohani, 1982). This method is very useful for selecting a site among alternative sites. The non-availability of baseline data is a serious short coming of the method.

ENERGETIC METHOD

In this method, the relationship between man and ecology is described using energy concept. Energy flows and storage are incorporated, with systems analysis and ecology, for environmental impact assessment (Odum, 1971). The shortcoming of this method is requirement of high degree of technical information and resources. Application of this technique for environmental, economic and hydrologic impacts of palm Bay Area in USA was presented by Barile (1977).

Flow Chart for EIA

Based on the proceedings sections, it can be summarized that for developing environmental indices to evaluate the impact assessment, various steps would be required (Bhatia, 1986). Though water resources impact assessment is very crucial for protection and conservation of the existing environment yet in India, till date systematic studies are very limited and sporadic. A number of WRPS are delayed, abandoned or are not taken up because of lack of EIA studies. As EIA is a very positive step towards healthier life, it should be thoroughly studied and used before WPRS in India are designed.



Simple Flow Chart for EIA

REFERENCES

1. Bhatia, K.K.S. and S.A. Abbasi, (1983), "Quantification of the Impact of Water Resources Projects on Environment - A Systems Approach", Proc. of Golden Jubilee Celebration Conference of the Geographical Society of India, held at Calcutta, Jan, 21-22, 1983., p. 28.

2. Bhatia, K.K.S. (1984), "Water Quality and Sediment Modelling in Surface Waters", National Institute of Hydrology, Roorkee Research Report, p. 125.

3. Bhatia, K.K.S. and A.K. Sikka (1986), "Various Procedures for Environmental Impact Assessment", in proc. of "Seminar on Env. Considerations in Planning of W.R. Projects", held at Roorkee on April 24-25, 1986, pp. II-1 to II-9.

4. Bhatia, K.K.S. & F.A. McBean, (1986), "Regression Modelling of Phosphorus Species for Diffused Sources" Journal of Instt. of Engrs (India), Env. Engg. Div., Oct. 1986-Feb. 1987, pp. 12-17.

5. Bhatia, K.K.S. and V.K. Lohani, (1987), "Hydro-environmental Indices - A Tool for Environmental Impact Assessment, Proc. of Nat. Seminar on 'Impact of Environmental Protection on Future Development, Nainital, April 6-8, 1987. pp 294-301.

6. Canter, L.,W., (1979), 'Water Resources Assessment - Methodology & Technology Source Book', Ann. Arbor. Michigan, U.S.A., p. 528.

7. Carpenter, R.A. (1986), 'Ecologinomics: A Guide to Sustainable Development, Proc. Int. Seminar on Environmental Impact Assessment of Water Resources Projects, Vol. II, Dec. 12-14, 1985, University of Roorkee, Roorkee, pp. 497-510.

8. Collison, R.I. (1981), "Environmental Impact Assessment - in Theory and in Practice", Journal of Water Science & Technology, Vol. 13, No. 6, 1981, pp. 107-105.

9. Dinesh Mohan (1986), "Environmental, Guidelines for planning Water Resources Development Projects", in Proc. of Seminar on env.

consideration in Planning of Water Resources Projects, Roorkee April 25-26, 1986, pp. II-10 to II-18.

10. Framji, K.K., (1986), "Irrigation Development and Environment", Commemorative Volume, CBIP Diamond Jubilee, 1927-87, Jan. 1987, New Delhi.

11. Goodland, R., (1985), 'Environmental Aspects of Hydro-Electric Power & Water Storage Projects in the Tropics", Proc. Int. Seminar on Environmental Impact Assessment of Water Resources Vol. III, Dec. 12-14, 1985, University of Roorkee, Roorkee. pp. 1-30.

12. Haber, D. (1979), "Preliminary Report on the Possibility of Developing and Using Alternate Indices", Technical Report of IHP Project 5.8, Div. of Water Sciences, UNESCO, Paris, p.6.

13. Lohani, B.N. (1982), "Water Resources Development and Typical Methodologies for Assessment of their Environmental Impacts" Journal of Indian Water Resources Society, pp. 1-14, Vol. 2, No. 2, 1982.

14. Lohani, B.N., (1985), 'Guidelines for Environmental Impact Assessment of Water Resources Projects in Developing Countries, Proc. Int. Seminar on Environmental Impact Assessment of water Resources Project, Vol. II, Dec. 12-14, 1985, University of Roorkee, Roorkee. pp. 593-609.

15. MacLarens, J.F. (1978), "A Review of Environmental Impact Methodologies", A report prepared by J.F. MacLarens Ltd., Ontario, Canada.

16. Maudgal, S., (1985), 'Guidelines for Environmental Impact Assessment of River Valley Projects", Deptt. of Environmental, Jan. 1985, p. 42.

17. Maudgal S., (1985), "Environmental Aspects of Water Resources Development Projects", Proc. of Indo Soviet Workshop on Evaluation & Modelling of Impacts on Environment of Water Res. Projects. pp. 1-49 to 1-67.

18. Mistry, J.F. and M.U. Purohit (1985), "Environmental Impact

of Mahi-Kadana Project" in Proc. of Int. Seminar on Env. Impact Assessment of WR Projects, held at Roorkee, Dec. 12-14, 1985, Vol. I, pp. 164-181.

19. Padhye, M.G. (1987), Article on 'Envrionment vs. Water Resources Development', Hindustan Times.

20. Pendse, Y.D. & Vidyassagar Rao, (1985), 'Integration of Environmental Concerns into Water Resources Project Planning, Proc. Int. Seminar on Environmental Impact Assessment of WR Projects, Vol. II, Dec. 12-14, 1985, University of Roorkee, Roorkee.

21. Pendse, Y.D. (1987), 'Envrionmental Aspects of Water Res. Development in India', Commemorative Volume, CBIP Diamond Jubilee 1927-87, Jan. 1987, New Delhi.

22. Rees, C.P. (1981), 'Guidelines for Environmental Impact Assessment of Dam and Reservoir Projects", in Journal of Water Sciences & Technology, Vol. 13, pp. 57-71, 1981.

23. Sarma, N.K. (1985), 'Environmental Issues in water Resources Devleopment" in Proc. of Indo Soviet Workshop on Evaluation and Modelling of Impacts on Environment of Water Resources Projects". held at New Delhi on Sept. 17-18, 1985, pp. I-1 to I-9.

24. Sarma, N.K. (1986), "Large Dams - A necessaary Developmental Choice', Bhagirath, Vol. 33, April 1986, pp. 55-63.

25. Singh, V.P. Panagioti, S.B., Arltaos, S. and Sundarayan (1985), 'Environmental Consideration for Water Resources Projects', Proc. Int./Seminar on Environmental Impact Assessment of Water Resources Projects Vol. II, Dec. 12-14, 1985, University of Roorkee, Roorkee, pp.

26. UNESCO (1984), "Hydro-Environmental Indices: A Review and Evaluation of their Use in the Assessment of the Environmental Impacts of Water Resources Technical Document in Hydrology, Working Group Report on IHP-II, Project A 3.2, UNESCO, 1984, p. 175.

APPENDIX - I

DATA REQUIRED FOR EIA STUDIES

Following data will be required for carrying out the study:

(A) Basic Information

- i) Existing land use in the catchment
  - a) Agricultural land
  - b) Forests
    - -Reserved
    - -Unreserved
  - c) Barren land
  - d) Other land use
- ii) Land use data of pre-construction period
- iii) Submerged area
  - a) Cultured land
  - b) forests
  - c) shrubs and fallow
  - d) area under ponds and lakes
  - e) residential area
  - f) other uses
- iv) Forest types in catchment area and submerged area
  - a) forest density
  - b) other vegetation
  - c) Rare Species if any
  - d) Forest area cleared for construction of roads, colonies and other uses of project
  - v) Total duration of construction and progress of various works during this period
- vi) Data regarding faunal resources of the region
  - a) type of wild animals
  - b) endangered species

c) any wild life sanctuary in the region

d) information regarding migration routes of animals

e) Hunting practices data, if any

f) measures proposed to salvage/rehabilitate

vii) Data regarding aquatic life

a) status of fisheries

b) effects on fish culture

c) measures to protect fisheries and other aquatic life

viii) Data regarding industrial development of the area

a) present status of industries

b) type of industries

c) sources of raw material

d) effects of construction on availability of raw material for industries

e) status of pollution to industries

ix) Population density (per sq. km.)

a) catchment

b) submerged area

c) command

x) Population affected by construction

a) Number of villages

b) Population

- scheduled caste
- scheduled tribes
- others

c) Occupation details

- Agriculturists
- Agricultural labour
- industrial labour
- forest labour
- artisans
- any other

d) Land Ownership
  - marginal farmers
  - small farmers
  - medium farmers
  - big farmers

e) Social status
  - income per family
  - details of schooling facilities
  - availability of market facilities
  - religious sentiments attached with specific areas
  - any other peculiar characteristics

xi) Resettlement details
  a) details of rehabilitation committee if any
  b) guidelines laid for rehabilitation, providing compensation in cash/kind
  c) resettlement plans
    - in existing villages
    - at new village sites
    - facilities being provided (school, post office, bank, police station, roads, drainage, water supply etc.)

xii) Details of developmental activities in affected areas
  a) small farmer development agency
  b) drought prone area programme
  c) integrated rural development programme
  d) tribal development programme

xiii) Information regarding tourism
  a) was the area a tourist resort ?
  b) details of religions, archaeological and recreational centre,wild life sanctuaries, national parks affected by the project.

xiv) Diseases/Health problems

a) details of endemic health problems due to soil water borne diseases

b) remedial measures taken

B. Hydrological and other data

i) Rainfall data cover years

ii) Streamflow values

iii) Sediment data/rate of siltation

iv) Water quality data

v) data relating to floods

vi) Ground water data including depth and seasonal variations, quality, status of use

vii) Proposed soil conservation

viii) problems of slips and slides on the periphery of the reservoir and remedial measures

C. Impact Assessment Data

i) Increases in irrigation facilities/irrigated area

ii) Crop yield values and improvements recorded

iii) Power generation and its impacts

iv) Flood protection activities and impacts

v) Water supply

vi) Ground Water recharge

vii) Employment generated

viii) Tourism attraction generated

ix) Alteration of weather and changes in micro climate

x) expected changes in ground water quality and proposed remedies

xi) expected waterlogging problems and remedies

xii) proposals for fisheries development and crocodile farming

xiii) mines, minerals, commercial timber and other natural resources coming under submergence

xiv) injurious minerals coming under submergence

xv) likely impact of reservoir loading of seismicity.

xvi) Broad details regarding growth of weeds (Salvinia, water hyacinth).

D. Any other relevant data including name of agencies already involved in carrying our impact studies of the project.