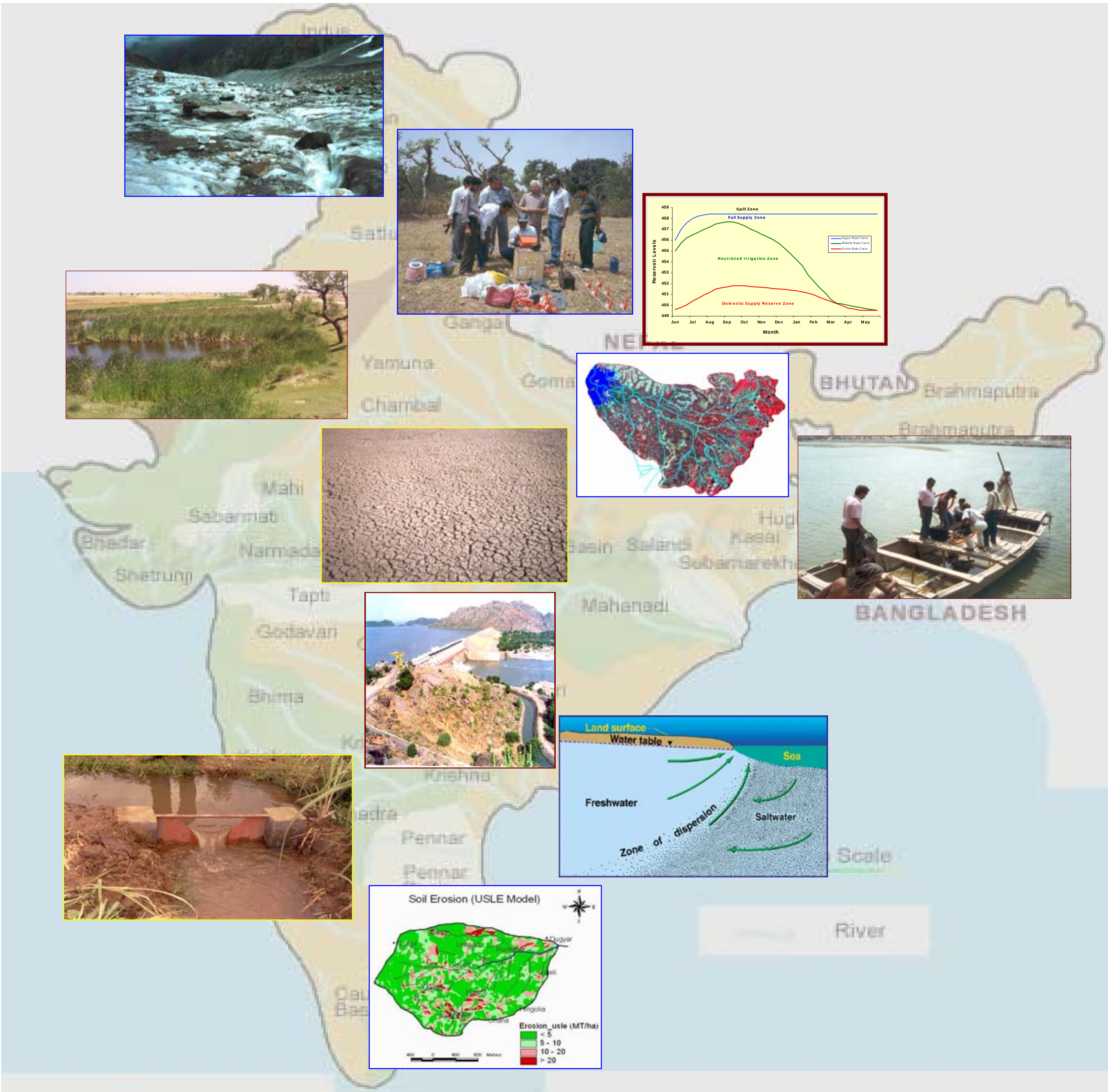
Implementable Technologies for Water Resources



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CONTENTS

ASSESMENT OF FLOOD IN GAUGED AND UNGAUGED CATCHMENTS

Estimation of flood magnitudes and their frequencies has been engaging attention of the engineers the world over since time immemorial, as this information is needed for design of different types of hydraulic structures. As per Indian design criteria, frequency based floods find their applications in estimation of design floods for almost all the types of hydraulic structures viz. small size dams, barrages, weirs, road and railway bridges, cross drainage structures, flood control structures etc., excluding large and intermediate size dams. For design of large and intermediate size dams probable maximum flood and standard project flood are adopted, respectively.

Whenever, rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable flood estimates directly. In such a situation, flood formulae developed for the region are one of the alternative methods for estimation of design floods, especially for small to medium size catchments. The conventional flood formulae developed for different regions of India are empirical in nature and do not provide flood estimates for desired return periods. Considering the wide applicability of the frequency based flood estimation approach and need for development of regional flood formulae for estimation of floods of various return periods for the ungauged catchments, regional flood formulae have been developed using the L-moment based approaches at the National Institute of Hydrology for various regions of the country such as: (i) Mahi and Sabarmati subzone 3(a), (ii) Lower Narmada and Tapi subzone 3(b), (iii) Upper Narmada and Tapi subzone 3(c), (iv) Mahanadi subzone 3(d), (v) Upper Godavari subzone3(e), (vi) Lower Godavari subzone 3(f), (vii) Krishna and Penner subzone 3(h), (viii) Middle Ganga plains subzone 1(f), (ix) Sone subzone 1(d) and (x) North Brahmaputra region.

TECHNOLOGY

Following two types of approaches are proposed for estimation of floods of various return periods for small to medium size gauged and ungauged catchments lying in the respective subzones/regions.

(i) Regional flood frequency relationships for estimation of floods of various return periods for gauged catchments, and

(ii) Regional flood formulae for estimation of floods of various return periods for ungauged catchments.

For Gauged Catchments

Procedure for estimation of floods of various return periods using regional flood frequency relationships developed for small size gauged catchments is mentioned below:

Step 1: Compute the mean annual peak flood (MAF) in cubic meter per second for the gauged catchment by taking the mean of the annual maximum peak flood values observed at the gauging site of the catchment during various years.

Step 2: Substitute the value of mean annual peak flood (MAF) computed in Step 1 and value of the desired return period (T) in the regional flood frequency relationship of the respective subzone/study area and compute the flood of desired return period (Q_T). For example, the regional flood frequency relationship for Subzone 1(f) is given below.

$$Subzone1(f), \quad Q_T = \left[47.534 - 46.8\left(-\ln(1-1/T)\right)^{0.01}\right] * MAF \; .... (1)$$

Where, Q_T is flood in cubic meter per second for T year return period, T is return period in years, and MAF is the mean annual peak flood for the catchment in cubic meter per second.

Alternatively, compute the flood of desired return period (T) by multiplying the value of mean annual peak flood (MAF) of the catchment, with the corresponding value of growth factor of the respective subzone/study area. For example, for subzone 1(f) the values growth factors for some of the commonly adopted return periods viz. 2, 10, 25, 50, 100 and 200 years are given below.

Values of growth factors (Q_T/MAF) for various subzones/regions

Sl. No.	**Subzone/ Region**	**Return Period (Years)**					
		2	**10**	**25**	**50**	**100**	**200**

1.	1(f)	0.906	1.776	2.209	2.527	2.840	3.151

For ungauged catchments

Procedure for estimation of floods of various return periods using the developed regional flood formulae for small size ungauged catchments lying in the respective subzones/regions is mentioned below:

Step 1: Find out area of the ungauged catchment (A) in square kilometres.

Step 2: Substitute the value of catchment area (A) mentioned at Step 1 and value of the desired return period (T), in the regional flood formula of the respective subzone/region. For example, the regional flood formula for subzone 1(f) is given below.

$$\text{Subzone}\,1(f),\quad Q_T = \left[34.842 - 34.304\left\{-\ln\left(1-\frac{1}{T}\right)\right\}^{0.01}\right]A^{1.084} \qquad (2)$$

Where, Q_T is flood in cubic meter per second for T year return period, T is return period in years, and A is the catchment area in square kilometres.

The Tabular forms and graphical representations of these regional flood formulae have also been prepared.

ENVIRONMENTAL IMPACT

As the above methodology is meant for estimation of floods of various return periods for small hydraulic structures and small-scale flood control measures etc. therefore, it will not have any adverse impact on the environment.

ECONOMICS

Overestimation of design flood results in increase of the cost of a hydraulic structure and under estimation of design flood leads to increased risk of failure of a hydraulic structure. Hence, the rational flood estimates obtained from the regional flood formulae will help in optimal economic design of the hydraulic structures and flood protection schemes. Therefore, it has both tangible and intangible benefits.

BENEFICIARIES

Central and state government organisations including other Professionals involved in planning, design and operation of water resources projects and flood protection works.

INTELLECTUAL PROPERTY RIGHTS

The regional flood frequency relationships for the gauged catchments and the regional flood formulae for ungauged catchments have been developed at the National Institute of Hydrology, Roorkee, therefore the Institute has the IPR of this technology.

ASSESMENT OF SPRING FLOW

India runs one of the largest rural water supply programmes in terms of both physical and financial dimensions and eighty percent of the water needs of the rural area are met from groundwater. Hilly areas though receive high rainfall, suffer due to lack of appropriate amount of water in respect of social, economic and health parameters. Springs, which are natural outlets for concentrated groundwater discharge, are ready, viable and clean sources of water. They are found in good numbers in the Himalayas, in the Western Ghats, in the North eastern region, in the Vindhyan Formation of Central India and in many other places. Great rivers like Cauvery and Jhelum originate from springs. However, there are disquieting reports that the spring flow has decreased to the tune of 50% in the Himalayas and places in the north eastern region during last two /three decades or so. Strategies based on hydrologic principles to rejuvenate and nurture spring flow will definitely contribute to augment the rural water supply, particularly in the hills where it may not be always possible to have adequate storage facility due to logistic reasons.

TECHNOLOGY

A few conceptual linear mathematical models that were developed during last two decades to assess spring flow assume that the spring flow is linearly proportional to the dynamic storage inside it and these models can accept only lumped recharge in the beginning. Bear model is one such popular model and is applicable for geologic formation having primary porosity. These models essentially provide a straight-line relationship during recession between spring flow and time on a semi-logarithm plot with spring flow on log scale (Eq.1, and Fig.1). The slope of the straight-line for one log cycle divided by 2.3 gives the value of the depletion time.

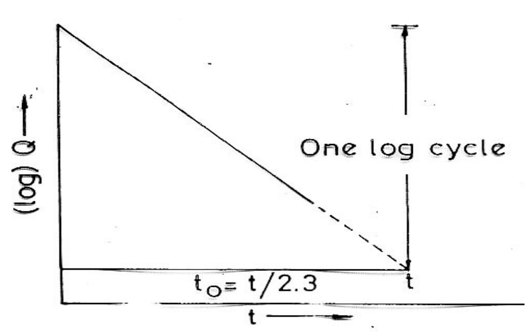


Fig. 1 Determination of depletion time

$$Q(t) = Q(o) \exp(-t/t_o) \qquad (1)$$

Where Q(t) = spring flow at time t during recession, Q(o)= any reference spring flow at a time previous to t during recession, t = is the time increment and t_o = a parameter of the spring representing recession characteristics and depends on geology and geomorphology relating aquifer geometry and aquifer properties and is designated as depletion time and has a dimension of time.

The Eq.(1) can be used to estimate the spring flow. The dynamic storage at any time during recession is Q(o).

The recharge to the spring flow domain between the end of one dry season and the beginning of the next one can be estimated by Eq. 2 following the principle of continuity.

$$AR = Q_2 t_0 - Q_1 t_0 + \int_{t_1}^{t_2} Qdt ....(2)$$

Where R is the recharge (LT^{-1}), A is the recharge area of the spring (L^2), t_1, t_2 are the instances of time at the end of one dry season and the beginning of the next one, and Q_1, Q_2 the spring discharges at t_1 and t_2 respectively.

At NIH, the Bear model has been adapted to simulate spring flow for the time-variant recharge. The adopted model can also be used as an inverse problem to compute the time variant recharge to the spring flow domain and depletion time from an available spring flow series. The monthly recharge was estimated for a spring emerging from karstified limestone aquifer from the monthly spring flow series of seven years. The annual recharge values for seven years computed earlier is in close agreement with the summation of the computed monthly recharge by the adapted Bear model.

ENVIRONMENTAL IMPACT

As the study of spring flow on the basis of hydrologic principles provides means to develop natural resources (forest, water and soil) and rejuvenation of the dying spring, `it will have positive effect on the environment.

ECONOMICS

Springs are the lifeline for the hilly areas and as such, the immediate tangible benefit of rejuvenation of springs will provide clean and sufficient water to rural hilly populace who usually suffer due to non-availability of drinking/potable water. As a consequence, their health and sanitation would improve and the womenfolk need not to travel far off places to fetch water. Further, it will save the construction of costly overhead storage tank in inhospitable, remote, earthquake prone hilly areas.

BENEFICIARIES

The chief beneficiary will be the hilly rural people, especially the womenfolk, who usually belong to economically backward section of India's population.

INTELLECTUAL PROPERTY RIGHTS

There is no element of intellectual property right. Involved in the use of this technology.

ASSESMENT OF SOIL EROSION

India's rivers constitute 5% of the world's river but they carry 35% sediments. We loose about 6000 million metric tons of topsoil annually due to water and wind erosion. This erosion in terms of fertilizer is equivalent of loosing 6 million tons of soil nutrients every year, which is approximately equal to the fertilizer we import every year. Eventually, a substantial portion of the eroded soil deposits in reservoirs and reduce valuable live storage and also make the reservoirs eutrophic. It is always economical to increase the life span of any reservoir by reducing the sedimentation by adopting appropriate soil conservation measures than constructing new reservoirs. Further, construction of new reservoirs is becoming technologically more complex, economically less attractive and less environment-friendly compared to earlier generation of completed projects.

TECHNOLOGY

The Universal Soil Loss Equation (USLE) developed by Agriculture Research Services, USA can be applied for quantification of sediment yield from the catchment area of a reservoir. The USLE states that the field soil loss A, is the product of six causative factors:

$$A = R\ K\ L\ S\ C\ P$$

Where, 'A' is computed soil loss in tons/hectare/year, R is the rainfall erosivity factor, K is a soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is a cover-management factor, and P is a supporting practices factor. This empirically based equation, derived from a large mass of field data, computes sheet and rill erosion.

The methodologies for the generation of information about the catchment area of a reservoir prone to excessive siltation with respect to various attributes of USLE, are as follows:

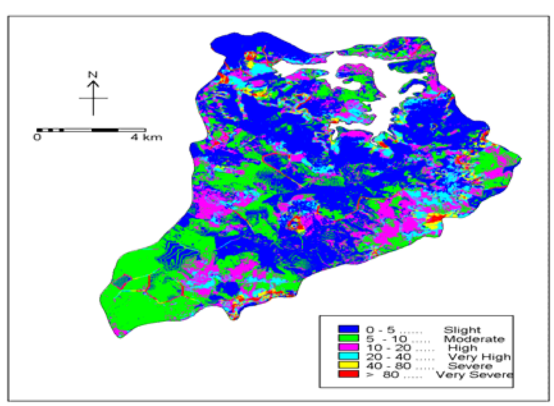


Figure -1: Expected Soil Loss in Bila Catchment

The IRS-IC Liss-3 digital data is used for the generation of land use map. The slope map could be prepared from the contour lines given in Survey of India toposheets and by preparing Digital Elevation Model (DEM). The information pertaining to rainfall and soils could be collected from IMD and State agencies. The data storage and analysis can be done by using ILWIS 3.0 Geographic Information System (GIS) and all the information related to all the six factors of the USLE are stored in different thematic map layers. Then, all the six factor-maps are multiplied together using "Map Calc" operation in ILWIS to obtain resultant map showing intensity of soil loss in tons/hectare/year. One such output raster map indicating soil erosion class is shown in figure-1. The intensity of soil loss is multiplied with corresponding area to have the total soil loss per year. Microsoft Excel software is usually used for tabulating the result in presentable format.

The map of the catchment depicting total soil loss could then be classified as different sub-zones representing different categories of severity of erosion e.g., slight erosion, moderate erosion, high erosion, severe erosion, very severe erosion etc. The map provides the intensity of soil erosion and area of the catchment under each sub-zones. Appropriate soil conservation measures may then be addressed to the areas of the catchment susceptible to high, severe or very severe erosion in order to check /reduce the soil erosion which is being deposited and reducing the live storage of the adjoining reservoir.

ENVIRONMENTAL IMPACT

As this technology is used to determine soil erosion from watersheds/catchments to take necessary measures for reducing topsoil loss and siltation in reservoirs, it will have positive effect on the environment.

ECONOMICS

Using this technology, a specific study on Bila reservoir having about 14000 hectare of catchment was accomplished. It is estimated that afforestation in the 50% of the barren land which is about 1280 ha of the catchment will increase the life of the reservoir by about 35%. It may be noted that the loss of water storage by reservoir sedimentation in India is of the order of 1-2% per year.

About Rs.1.0 lakh was the expenditure for studying Bila reservoir catchment including the cost of the remotely sensed data but excluding the cost of ILWIS-GIS software. But, the benefit that would have been accrued by controlling soil erosion including reduction of reservoir sedimentation is expected to be much more.

BENEFICIARIES

The government agencies dealing with the maintenance and operation of reservoirs and soil conservation/watershed management agencies in a catchment will be direct beneficiaries. The savings of precious live storage of the reservoirs will ensure larger storage in the reservoir for various uses.

INTELLECTUAL PROPERTY RIGHTS

There is no element of Intellectual Property Rights in the use of this technology.

DESIGN OF RADIAL COLLECTOR WELL

The water of most of the Indian rivers is polluted. A huge amount of expenditure is made to treat the water for removal of suspended material and bacteria before supplying it for municipal consumption.

Groundwater is considered to be clean and safe source of water supply. But, in some geologic environments, the aquifer thickness may not be sufficient to supply the required volume of water to vertical wells, even though the aquifer is hydraulically connected to a nearby surface-water body. A typical example occurs in a river valley where thin alluvial deposits overlie bedrock. Even though the hydraulic conductivity of the sediment is excellent, the transmissivity is severely limited because the deposits are so thin. In other situations, a thin layer of fresh water may overlie saline or brackish water. Deep wells at this site would cause upconing of the saline water, thereby destroying water quality.

Under these conditions, radial collector wells can be placed in permeable alluvial materials either adjacent to a water body or beneath its bed to withdraw sufficient volume of good quality water.

TECHNOLOGY

A radial collector well system comprises a series of horizontal wells discharging water into a central large diameter well known as caisson (Fig.1). A typical caisson is about 4 m in diameter and 25 to 40 m deep. The well may extend up to the shallow bedrock or clay layer. It is made of reinforced cement concrete sections, brick or stone masonry. The bottom of the caisson is sealed with a concrete plug. Portholes, to accommodate radial wells, are

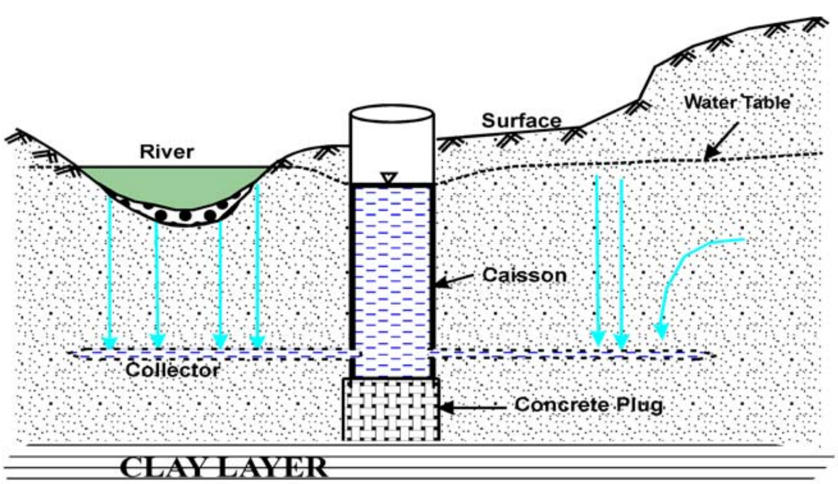


Fig. 1: A radial collector well system.

provided about 1m above the bottom of the caisson.

Near the bottom of the caisson, horizontal well screens are projected radially. The diameters of the horizontal screens vary from 15-60 cm, depending on their estimated yield and design velocities. Each pipe is provided with a well point. The well screen assembly is pushed into the aquifer with the help of hydraulic jacks aided by an air compressor.

Water enters from the surrounding aquifer, flows into the central caisson during pumping. Entrance velocities in radial wells are often that of the order of 3cm/sec. Vertical turbine pump or submersible pump with control switches located away from the pump is provided to pump water from the collector well.

The hydraulic design of the radial collector well, i.e., length and diameter of radial collectors and caisson, depends on the required well yield. A three-dimension groundwater flow model for inhomogeneous riverbank material has been developed to compute the flow to the well by changing the length and diameter of the radials. A provision has been kept in the software to compute the entrance velocity into the well. Entrance velocity affects the performance of the well.

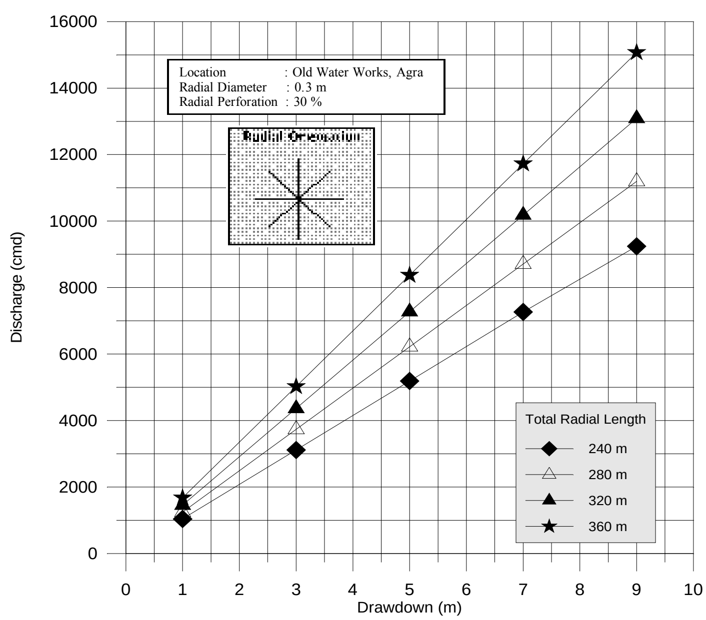


Fig. 2: Variation of discharge with drawdown at Old Water Works, Agra

The model was implemented to design the radial collector well for water supply to Agra town. It was found that a radial collector well, at Old Water Works, with eight radial pipes of diameter 0.3 m with 30% perforations and having total length of 320m can supply 10180 m^3 of water per day for a drawdown of 7m in the caisson. The discharge can be increased to 15072 m^3 per day by increasing the length of the total lengths of the radials to 360 m. The relation of well discharge to drawdown is shown in Figure 2.

ENVIRONMENTAL IMPACT

Radial collector wells are constructed to get good quality water as compared to polluted water flowing in the nearby river. The soils present between the riverbed and the screen of the collectors act as natural filter media and remove most of the turbidity and bacteria / viruses present in the polluted river water. The total removal of bacteria / viruses depends on the distance of the well from the riverbank.

ECONOMICS

Radial collector wells improve the quality of water, thereby reducing the cost of treatment of water to a large extent. Also the chances of supply of untreated water due to failure of Treatment Plants are reduced. Therefore, it will have tangible and intangible benefits.

BENEFICIARIES

Central and State government and non-governmental organizations responsible for supply of clean drinking water, such as Urban Water Supply Departments and Public Health Departments

INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee has the Intellectual Property Rights being the developer of the methodology.

ESTIMATION OF GROUNDWATER RECHARGE

The utilizable water resources of India are estimated to be $112*10^6$ ha m out of which $69*10^6$ ha m are surface water resources and $43*10^6$ ha m are groundwater resources. Due to uneven distribution of rainfall both in time and space, the surface water resources are also unevenly distributed. The development and over-exploitation of groundwater resources in certain parts of the country have raised the concern and need for judicious and scientific resource assessment, management and conservation.

The Groundwater Estimation Committee (GEC, 1997) recommended that the groundwater recharge should be estimated based on groundwater level fluctuation method. This Committee proposed several improvements in the existing methodology based on groundwater level fluctuation approach.

TECHNOLOGY

The methodologies adopted for computing groundwater resources, are generally based on the hydrologic budget techniques. The estimation of groundwater balance of a region requires quantification of all individual inflows to or outflows from a groundwater system and change in groundwater storage over a given time period. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system. Considering the various inflow and outflow components in a given study area, the groundwater balance equation can be written as:

$$R_r + R_c + R_i + R_t + S_i + I_g = E_t + T_p + S_e + O_g + \Delta S \qquad (1)$$

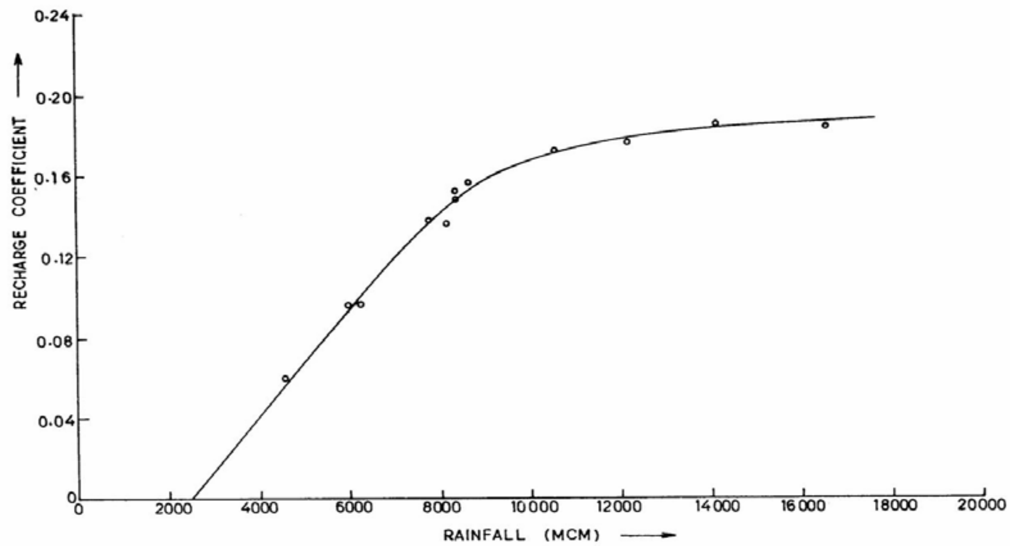
Where, R_r is recharge from rainfall; R_c recharge from canal seepage; R_i recharge from field irrigation; R_t recharge from tanks; S_i influent seepage from rivers; I_g inflow from other basins; E_t evapotranspiration from groundwater; T_p draft from groundwater; S_e effluent seepage to rivers; O_g outflow to other basins; and ΔS is the change in groundwater storage. Preferably, all elements of the groundwater balance equation should be computed using independent methods.

Groundwater balance study is a convenient way of establishing the rainfall recharge coefficient, as well as to cross check the accuracy of the various prevalent methods for the estimation of groundwater losses and recharge from other sources. By quantifying all the inflow/outflow components of a groundwater system, one can determine which particular component has the most significant effect on the groundwater flow regime. Alternatively, a groundwater balance study may be used to compute one unknown component (e.g. the rainfall recharge) of the groundwater balance equation, when all other components are known. In this manner, the study of groundwater balance has a significant role in planning a rational groundwater development of a region.

National Institute of Hydrology conducted a detailed seasonal groundwater balance study in Upper Ganga Canal command area for the period 1972-73 to 1983-84 to determine groundwater recharge from rainfall. It was observed that as the rainfall increases, the quantity of recharge also increases but the increase is not linearly proportional. The recharge coefficient (based upon the rainfall in monsoon season) was found to vary between 0.05 and 0.19 for the study area. An empirical relationship (similar to Chaturvedi formula) has been developed by fitting the estimated values of rainfall recharge and the corresponding values of monsoon rainfall through the non-linear regression technique.

$$R_r = 0.63(P - 15.28)^{0.76} \qquad (2)$$

Where, R_r is groundwater recharge from rainfall in monsoon season (inch) and P is the mean rainfall in monsoon season (inch). The relative errors (%) in the estimation of rainfall recharge computed from the above empirical relationship were compared with groundwater balance study. In almost all the years, the relative error was found to be less than 8%. Therefore, Eq.-2 can conveniently be used for better and quick assessment of natural groundwater recharge in Upper Ganga Canal command area.



VARIATION OF RECHARGE COEFFICIENT WITH RAINFALL

ENVIRONMENTAL IMPACT

The groundwater balance studies will help in planning sustainable development of groundwater resources that will have only the positive impact on the environment.

ECONOMICS

The implementation of this technique will lead to reasonable assessment of groundwater resources in the country so that judicious and scientific management of groundwater resources could be made. Thus, it will have considerable benefits.

BENEFICIARIES

All central and state government groundwater organisations, semi-government organisations; NGOs and public in general concerned with groundwater development programmes.

INTELLECTUAL PROPERTY RIGHTS

There is no element of Intellectual Property Rights in this study.

ESTIMATION OF IRRIGATION RETURN FLOW

Excess water application, over and above plant water requirement and soil-water detainment, either goes waste if the quantity is more or replenishes groundwater for subsequent uses. Use of optimal quantity of irrigation water satisfying crop water requirement will not only save water for irrigation of larger area but will also save money against withdrawal of water and restrict excess water from flowing to the aquifer (which may cause water-logging in command areas).

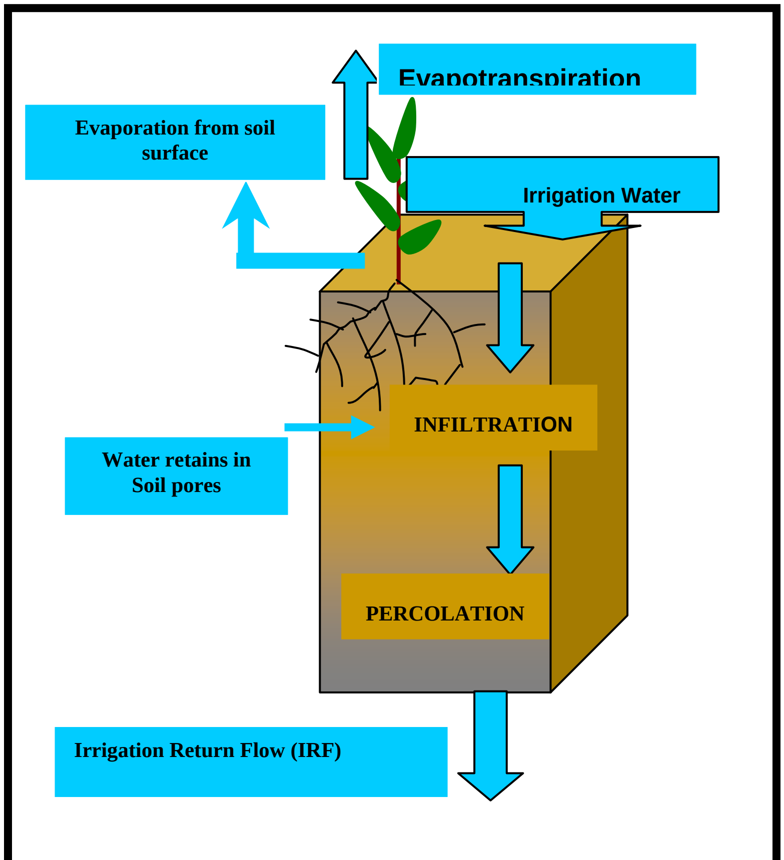


FIG 1: SCHEMATIC DIAGRAM OF COMPONENTS OF ARTIFICIAL IRRIGATION WATER APPLICATION

TECHNOLOGY

Irrigation Return Flow (IRF) is part of artificially applied water that is not consumed by plants or evaporation, and that eventually "returns" to an aquifer or surface water body. That means, when water is applied over a crop field in the form of irrigation water, it will first infiltrate and percolate to the soil, a part of water will evaporate from the soil surface, another part of water will be consumed by crop through its roots and will transpire to atmosphere (evapotranspiration), yet another part of water will be retained by the soil in the unsaturated zone, the remaining part of which will flow to the surface water body or an aquifer which is termed as IRF. Figure 1 describes a schematic component of Irrigation Return Flow of artificial applied water.

The question is; how to estimate the component of IRF? Neither the field measurements of all components nor the measurement of IRF component alone is an easy and straightforward task. If we can make an estimation of each shareholder of an irrigation water application separately except the IRF component and put those estimated components in the form of water balance equation for a given period of time, the unknown component, IRF, can then easily be computed. This method is known as Soil-Moisture Modeling (SMM) Approach. In SMM approach, change of soil moisture in the unsaturated zone (the zone in which roots of crops and plants lie) for a given input and forcing outputs (such as crop's uptake, rejected outflow etc.) over a period of time is estimated. The rejected flow from the unsaturated zone is the IRF.

Adopting the concept of SMM, a process level model has been developed at the Institute that gives estimation of IRF from a crop field (Fig.1) at a micro level and gives estimation of IRF from a command area (Fig.2) for an artificial applied water also in an integrated form.

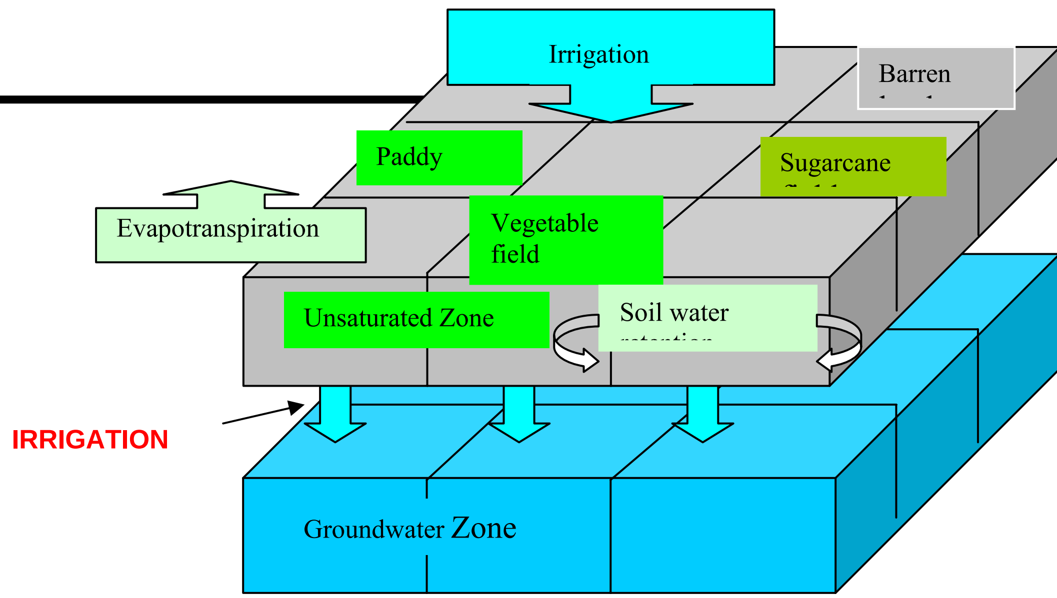


Figure 2: Schematic representation of an irrigation command showing components of artificial irrigation application.

A numerical model based on one-dimensional Richard's equation formed the basis of development of the methodology. The methodology is as follows:

i) Assess the land-use pattern and the crop types including their rotation and base period of a command area using Remote Sensing data and GIS information or from the statistical record.
ii) Delineate the soil types including their texture.
iii) Group them according to the crop types.

iv) Determine the soil properties; such as, saturated hydraulic conductivity (K_s), Specific gravity of soil, Particle density, Bulk density, Saturated moisture content, Wilting point, Field capacity for each soil group.

v) Calculate evapotranspiration from Pan evaporation data, or empirical formula for estimation of evapotranspiration using meteorological data.

vi) Obtain the field data, such as, irrigation water application (from Inflow/Outflow measurement of a field).

vii) Discretize the depth below the ground surface up to the groundwater tables into different vertical grids.

viii) Use Richard's equation with sink term for developing the source code in any Computer language. The source code coupled with algebraic equations forms the mathematical model.

ix) Calibrate the model with one set of soil moisture data and then validate with two or more sets of data. Emphasis should be given for matching the moving front as well as the recession front. If matching is not obtained, adjust the soil properties in order to obtain a reasonable match.

x) Run the validated model for the complete base period (sowing to harvesting) of the crops.

xi) The volume of flow computed at the end of each time step, as vertical rejection of flow from the soil column to the actual water infiltrated or applied, is the return flow of the given application of water.

xii) Integrate the processes of single column according to the soil groups, crop types and depth of water table to obtain the return flow from the whole command. Volume of water computed as return flow to the volume of water actually applied over irrigation command in terms of percent would give the percent irrigation return flow from that command.

xiii) Perform the water balance check either on a single column basis or of the command area as a whole.

This technique has been developed, used and validated at the institute.

ENVIRONMENTAL IMPACT

Application of the proposed methodology does not effect any change in the natural processes. Hence, there is no threat to the environmental issues.

ECONOMICS

This is one of the major components based on which most of the groundwater related schemes and agricultural schemes are developed and decided. Correct application of irrigation water and a pre-decided allocation in the form of IRF would save lots of water to go unutilized and would increase irrigation efficiency as well besides indirect benefit on monitory side.

Photograph showing Cropping pattern in a Command area.

BENEFICIARIES

Planners and decision-makers of Surface and Groundwater, and Agricultural sectors directly, and agricultural farmers indirectly.

INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee has the Intellectual Property Rights being the developer of the methodology.

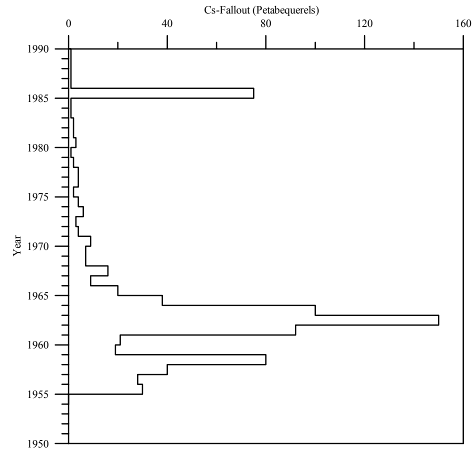
EXPECTED LIFE OF WATER BODIES

Over last few years, studies of recent lakes and reservoir sediments have become of increasing importance in many aspects of environmental appraisal. Sediment entered into the water bodies deposits slowly on the lake floor in natural process of sedimentation and reduces its storage capacity, encourages biotic growth and affects the functioning of lake ecosystem. As the accurate sedimentation rate is of vital importance not only for estimating the useful life of the water bodies, but also to prepare strategies for management and conservation of the water bodies; it is therefore, a matter of great concern to the authorities to know the accurate sedimentation rates and causes of higher rate of sedimentation in order to save the water bodies from diminishing.

TECHNOLOGY

Various techniques such as bathymetric survey, sediment balance method, stratigraphic method, remote sensing and radiometric dating techniques exist to determine the sedimentation rate, but radiometric dating techniques have proved to be one of the most reliable tools for the estimation of sedimentation rate in water bodies and are being used the world over. Although, several radioisotopes are useful in geochronological studies of lake sediment that occur naturally and artificially in the environment, among all the radioisotopes, ^{137}Cs (Cesium-137) and ^{210}Pb (Lead-210) have been found very useful for the dating of lakes/reservoirs sediment. One can determine very accurately the sedimentation rate in the past 100 years of water bodies using ^{210}Pb dating technique. In case of ^{137}Cs technique, sedimentation rate can be determined for the last 50 years with high accuracy, because natural fall out of ^{137}Cs has been found considerable in the years 1953-54, 1957-58, 1963-64, 1978-79, 1986-87 due to testing of the various atomic devices and the nuclear accidents. These peak years act as a marker horizon in determining the sedimentation rate. In case of 210Pb, dating of sediment, the unsupported activity of ^{210} Pb is determined and the slope of ^{210}Pb, activities versus depth enables to determine the sedimentation rate accurately. ^{210}Pb techniques can be applied in case of low or high sedimentation rates while ^{137}Cs technique may fail in case of high sedimentation rates (>2 cm/yr).

A view of sediment cores collected from a lake



Fallout Pattern of ^{137}Cs in Northern Hemisphere

Average sedimentation rate on weighted area basis is determined from sedimentation rates estimated at different locations in water body and then expected useful life is determined accurately by dividing the average depth of water body by average sedimentation rate. The Institute has employed this technology to determine the sedimentation rates and expected useful life of Nainital, Bhimtal, Naukuchiyatal, Sat-tal lakes in Uttaranchal; Mansar and Dal-Nagin lake in Jammu and Kashmir; Sagar and Bhopal lakes in Madhya Pradesh and Barapani reservoir in Meghalaya.

ENVIRONMENTAL IMPACT

As this technology involves the use of environmental isotopes (natural level activity), therefore, it does not have any adverse impact on environment.

ECONOMICS

Generally, 10 sediment cores of approximately more than 40 cm are required to be collected from a water body 1 km^2. The total expenditure in collection and dating of a sediment core using ^{137}Cs technique will be around Rs. 2.00 lakh for water body of 1km^2 while it will be around Rs. 3.00 lakh for ^{210}Pb technique (excluding travel charges).

BENEFICIARIES

Lake and reservoir development authorities.

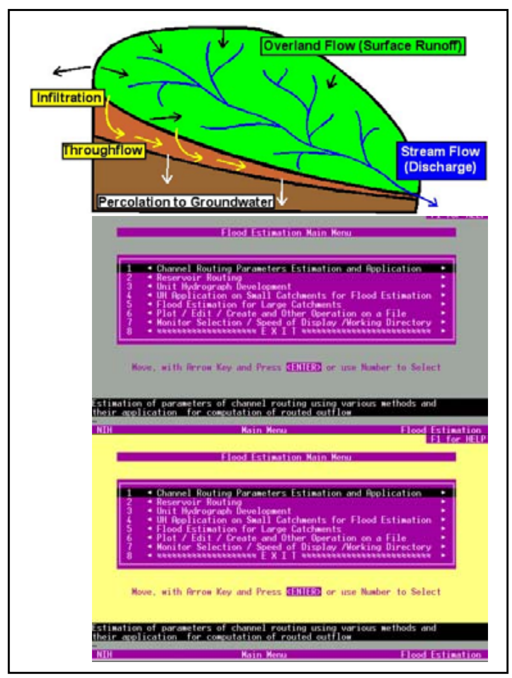
INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee, has the Intellectual Property Rights being the developer of the methodology.

FLOOD ESTIMATION

Flood estimation is one of the most important components of water resources project planning, design and operation. Unit hydrograph theory may be used to estimate the flood for the small catchments up to the size of 5000 sq. km. with reasonable accuracy. However, for the catchments having area more than 5000 sq. km., the principle of Unit Hydrograph cannot be applied considering catchment as a single unit. A network model may then be developed wherein the flood hydrograph be computed for each sub-catchment and the combined contributions from each sub catchment be routed through the respective river reaches or reservoirs using an appropriate flood routing technique to estimate the flood for the large size catchment.

This package deals with various options for flood estimation for large as well as small and medium sized catchments using popular unit hydrograph approach and reservoir and channel routing procedures. Package includes most of the commonly used approaches for unit hydrograph derivation, change of unit duration of unit hydrograph, development and use of dimensionless unit hydrograph, and development of unit hydrograph for ungauged catchments. It also deals with processing and analysis of rainfall and runoff data and flood estimation for ungauged catchments.



The software is user-friendly and provides on line help for using various options and sub-options. All the important information which may be helpful for analysing the results are displayed on the computer screen. For flood estimation for large catchments, package utilises networking approach in which flood of individual catchment is calculated and then routed through individual channel reach or reservoir to get the final flood hydrograph of the catchment. Package has the capability to compute either design flood or normal flood depending upon the rainfall input.

TECHNOLOGY

This package deals with various options for flood estimation for large as well as small and medium sized catchments using unit hydrograph approach and reservoir and channel routing procedures. It also deals with processing and analysis of rainfall and runoff data and flood estimation for ungauged catchments. These options are categorized in six main groups dealing with:

(i) Channel routing parameters estimation and application,

(ii) Reservoir routing,

(iii) Unit hydrograph development,

(iv) UH application on small catchment for flood estimation,

(v) Flood estimation for large catchment and,

(vi) Plotting and other file related and display operations.

Under each main category there are sub categories for different options. The interactive software package incorporates the above aspects through options for various methods flood routing and unit hydrograph derivation. Also, the options for calibration of unit hydrograph parameters for the various sub catchments and for calibration of routing parameters for different river reaches from the historical records are provided in the package. A user manual describes, in brief, methodologies adopted for various options and demonstrates the applications of the software package for the various options with the help of illustrative examples whose sample input and output are provided in the package.

ENVIRONMENTAL IMPACT

The package may be utilised for the estimation of flood hydrographs for small and large catchments. The design flood estimates may be obtained for small, medium and large water resources projects using the appropriate options available in the software. This will have positive impact on the environment.

ECONOMICS

The estimation of flood for small as well as large catchments is a prerequisite for any water resources project. The correct estimate of the flood has a direct impact on the economics of any project. Overestimation of flood may result in construction of uneconomical structures. However, underestimation of floods may lead to the failure of the structure. Thus, the reasonably accurate estimate of design flood may be helpful for designing and construction of economically as well as technically feasible structures. Thus it will have tangible and intangible benefits

BENEFICIARIES

The direct beneficiaries of this technology would be the Engineers, planners involved in the planning, designing and construction of the small, medium and large water resources structures. Furthermore, it may be used for designing the culverts highway and railway bridges and other cross drainage works.

INTELLECTUAL PROPERTY RIGHTS

The methodology and the software for the technology have been developed at National Institute of Hydrology, Roorkee. Therefore, the Institute reserves the IPR of this technology.

GEOMORPHOLOGICAL INSTANTANEOUS UNIT HYDROGRAPH (GIUH)

Estimation of runoff response from ungauged catchments has been an important subject of research for planning, development and operation of various water resources projects. The conventional techniques of derivation of unit hydrograph (UH) require historical rainfall-runoff data. Due to obvious reasons, adequate runoff data are, generally not available for many of the small size catchments. Indirect inferences through regionalization are sought for such types of the ungauged catchments. For estimation of runoff response of an ungauged catchment, resulting from a rainfall event, geomorphological instantaneous unit hydrograph (GIUH) approach is getting popular because of its direct application to an ungauged catchment. It avoids adoption of tedious methods of regionalization of unit hydrograph; wherein, the historical rainfall-runoff data of a number of gauged catchments are required to be analysed. As a first step in the direction of using geomorphologic characteristics for this purpose, the concept of a triangular shaped geomorphologic instantaneous unit hydrograph (GIUH) was introduced by Rodriguez-Iturbe and Valdes in the year 1979. The GIUH approach has many advantages over the regionalization techniques. It avoids requirement of flow data and computations for neighboring gauged catchments in the region as well as updating of the parameters. Another advantage of the GIUH approach is its potential of deriving the UH using only the information obtainable from topographic maps or remote sensing, possibly linked with geographic information system (GIS) and digital elevation model (DEM).

TECHNOLOGY

The GIUH derived from geomorphological characteristics of a catchment has been related to the parameters of Clark IUH model as well as Nash IUH model for deriving its complete shape through non-linear optimisation. The DSRO hydrographs estimated by the GIUH based Clark and Nash models may be compared with the DSRO hydrographs computed by the Clark IUH model option of the HEC-1 package and the original Nash IUH model by employing some of the commonly used error functions. Sensitivity analysis of the GIUH based models may be conducted with the objective to identify the geomorphological and other model parameters which are more sensitive in estimation of peak of unit hydrographs computed by the GIUH based models, so that these parameters may be evaluated with more precision for accurate estimation of flood hydrographs for the ungauged catchments. For applying this technique the required geomorphological parameters of a catchment may be computed manually or through a GIS software.

These models have been applied to some of the sub-basins such as Ajay river basin up to Sarath in Jharkhand, Krishna-Wunna sub-basin up to bridge No. 807 of Godavari basin In Maharashtra, Tons river basin up to Kishau dam site in Uttranchal, some sub-basins of river Narmada.

ENVIRONMENTAL IMPACT

As the above methodology is meant for estimation of floods or design floods for the ungauged catchments, it may not lead to major environmental effects directly. However, if the technology is applied to design the water resources structures then there is need to carry out environmental impact assessment studies before taking up the construction of such structures.

ECONOMICS

Overestimation of design flood results in increase of the cost of a hydraulic structure whereas under estimation of design flood may increase the risk of failure of a hydraulic structure. The technology may be applied to provide rational estimate of design flood particularly for the small ungauged catchments, as a large number of such catchments are ungauged in India. Thus, the technology will be helpful for planning, designing, and operation of the water resources projects in the ungauged catchments. Furthermore, the technology may also be applied for designing small culverts, bridges, cross-drainage works and flood protection structures etc. From the application of this technology there will be intangible benefits.

BENEFICIARIES

Engineers, Scientists and other Professionals involved in planning, design and operation of water resources projects and flood management works will be the beneficiaries.

INTELLECTUAL PROPERTY RIGHTS

The GIUH based Clark and Nash models have been developed at the National Institute of Hydrology, Roorkee. Therefore, the Institute reserves the IPR of this technology.

GROUNDWATER SALINITY IN COASTAL AQUIFERS

The Indian peninsula has a long coastline of about 7000 km. Water resources in these coastal regions have a special meaning since any developmental activity largely depends upon the availability of freshwater to meet the industrial, agricultural and domestic requirements. Groundwater is an important natural resource of freshwater for human consumption in these areas and is increasingly being used to meet the major bulk of water supply demands. However, coastal aquifers are vulnerable to contamination from saline water. Major sources of groundwater salinity in a coastal aquifer may be either one or a combination of the following:

- Intrusion of saltwater from the sea due to extensive lowering of the water table
- Seawater present in aquifers from past geologic times
- Presence of salt domes in geologic formations
- Salts in water concentrated by evaporation in tidal lagoons, playas or other enclosures (e.g. aquaculture tanks)

As more and more coastal areas are developed, and groundwater withdrawals increase, the heavier saltwater intrudes further into a freshwater aquifer, and renders the saline water unfit for human use. Once the freshwater aquifer turns saline, it becomes extremely difficult to reclaim the much-needed freshwater. In India, most of the states lying along the coast are facing this threatening scenario. In order to avoid the costly and irreversible loss of these precious freshwater reservoirs, there is an imperative need to plan a sustainable groundwater development of coastal aquifers. Such groundwater development calls for a planned pumping policy keeping in view the salinity source, and, appropriate measures to control saltwater intrusion in coastal aquifers.

TECHNOLOGY

To combat the problem of saltwater encroachment, various alternative preventive/remedial strategies may be employed, as follows:

- Artificial recharge
- Controlled extraction pattern

- Injection/Extraction hydraulic barriers
- Physical subsurface barriers

In order to plan an optimal pumping/recharge policy in accordance with above strategies, it is essential to have prior information about the behavior of the freshwater-saltwater interface in response to the various possible pumping/recharge policies. In such cases, mathematical models that can simulate the behavior of a coastal aquifer in response to a given hydrologic scenario, prove to be indispensable tools in formulating a sound management policy. As an example, the brief details of a study carried out by the National Institute of Hydrology, Roorkee, in collaboration with Ground Water Department, Andhra Pradesh, on Freshwater Saltwater Interaction in the Coastal Aquifer System in Krishna Delta, Andhra Pradesh are described below.

Krishna Delta is an agricultural area, well known for its rich paddy yields. Lately, due to dwindling supply of canal water for irrigation, groundwater is being tapped on a larger scale. The above project was taken up on account of numerous reports made by farmers of an increase in groundwater salinity in areas that were previously yielding fresh groundwater.

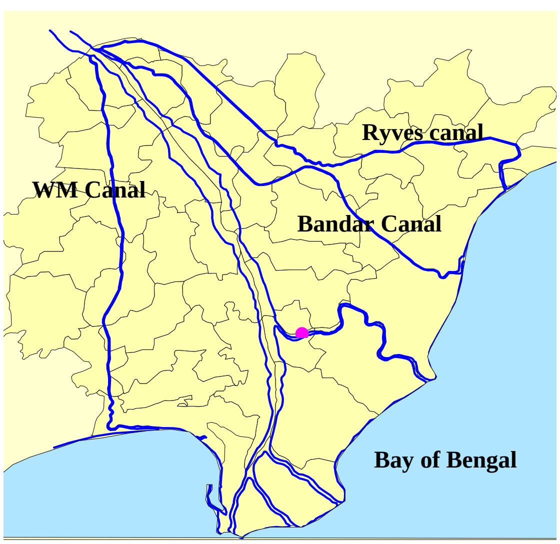


Fig.1:A Coastal Area (Krishna Delta) **Fig. 2 Recharge well at Mopidevi**

The triangular-shaped study area in Krishna Delta (Fig.1) consisted of the region bounded by WM Canal in Western Delta, Ryves Canal in Eastern Delta, and Bay of Bengal on the seaward side. The ultimate goals of the project were to gain an understanding of the hydrogeology of aquifer system in Krishna Delta, analyse reasons for water salinity in the area, develop numerical model of groundwater aquifer system and devise possible remedial measures in the area.

To achieve the project goals, extensive groundwater monitoring and field investigations were conducted. Hydrogeologic investigations showed that the aquifer system consists of three aquifer zones, which are interconnected at places. The fourth deep-seated aquifer is largely isolated from the other aquifer zones. Hydro-chemical *and* isotopic analyses of groundwater samples from the study area revealed that the existing salinity (which ranges from slight to moderately brackish in shallow and middle aquifer zones, and, highly brackish to saline in deeper zones), is mainly due to the migration of coastline over the geologic time scale. Freshwater recharge arising from Prakasam reservoir and canal irrigation, besides rainfall, has lead to freshening of previously saline groundwater.

Numerical modeling of saltwater transport along section AA' (refer Fig. 1) revealed that a decrease in freshwater recharge to the aquifer system would slowly but eventually lead to encroachment of saltwater from the existing saltwater zones into the adjacent freshwater zones in the shallow and middle aquifers. Already, the flow in River Krishna and discharge of water into the canal system has declined, on account of increasing upstream usage, which in turn has reduced the groundwater recharge arising from canal seepage and irrigation return flow.

To test the effectiveness of artificial recharge through recharge wells, a complex of 5 recharge well structures (refer Fig. 2) were constructed at Ayodhya Village in Mopidevi Mandal. These wells were located in three out fall drains, which discharge significant quantities of water into the river when the canals are operational. Analyses of groundwater samples from observation wells in the area revealed a decrease in groundwater salinity in the surrounding area within a radius of 500 m, as a result of artificial recharge.

ENVIRONMENTAL IMPACT

It will not have any adverse effect on the environment.

ECONOMICS

This technique helps in managing the groundwater resources in the coastal areas, therefore it will have tangible and intangible benefits.

BENEFICIARIES

Central and state groundwater development agencies including farmers and the local population of the region.

INTELLECTUAL PROPERTY RIGHTS

There is no such element involved.

HYDROPOWER POTENTIAL IN THE HIMALAYAN REGION

For preparing a master plan for small hydropower development, an estimate of power potential at each prospective site should be known a priory. This estimate of power potential is based on the reliability of water flow at respective sites. Reliability can be estimated from the streamflow record, the characteristics of which can be depicted by a flow duration curve.

Flow duration curves for the sites for which adequate flow data are available can be directly developed. Flows for various levels of dependability for these gauged sites may be estimated from these curves. It is quite obvious that most of the prospective sites for hydropower projects are likely to be ungauged, especially for smaller projects located in developing countries. Thus for such potential sites, there are either insignificant data or no flow data for such analyses.

To derive a flow duration curve for a location on a stream, for which adequate flow data are not available, regional analysis approach can be adopted. Regional flow duration curves are developed for a region as a whole. This region is a comparatively bigger area, but hydrometerologically homogeneous in character. Regional models are developed on the basis of data available for a few other gauged sites in the same region or transposed from similar nearby region. Such models are employed to compute flow duration curves for ungauged locations of interest in a region. Availability of such regional flow duration models is of paramount significance in estimating the potential of hydropower in vast hilly regions of the country and also helps in avoiding time delays in the implementation of individual small hydropower projects.

The primary objective of this technology is to develop flow duration models for regions having potential hydropower sites in various parts of the country.

TECHNOLOGY

A flow duration curve for a site in an ungauged catchment is derived using regionalization procedure. To this end, a region is identified such that it is comparatively a bigger area than the individual ungauged catchments, but adequately small so that homogeneous hydrometeorological conditions generally exist across the region. And for this purpose, the available classification of hydro-meteorological homogeneous regions in the country (CWC, 1983) can be considered. The institute has developed the technology and used it in various states like Jammu & Kashmir, Himachal Pradesh, Bihar, West Bengal, Sikkim, Assam, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram and Tripura. The study area in these states covers the foothills of Himalayan and Sub-Himalayan ranges. However, in the state of Bihar some portion of the hilly region of Hazaribagh Ranges in the Central India is also included in the study area.

The study area was divided into nine regions. All the gauged sites in the region are first identified. Then, on the basis of the flow characteristics at these sites, a model representing the conditions of flow regime throughout the region is evolved. The flow duration curves are constructed from non-dimensional flows (flows in terms of mean runoff $[Q/Q_{mean}]$) as it is a more convenient form of comparison and in case of inadequate data for some sites, data from all the sites of the region can be pooled up for model development. The power transformation technique is used to transform the non-dimensional flow data to the normally distributed data series. The formulae for the power transformation of the non-dimensional flows (Q/Q_{mean}) are given by,

$$W = [(Q/Q_{mean})^{\lambda}-1]/\lambda \quad \text{when } \lambda \neq 0$$
$$W = \ln(Q/Q_{mean}) \quad \text{when } \lambda = 0$$

where Q and W stand for the corresponding elements of original and the transformed series, respectively. And λ is an exponent, which can be determined by trial and error or any other suitable optimization technique so as to yield a normal W series.

The non-dimensional flow for any desired level of dependability may be estimated using the normal probability distribution and subsequently using the inverse of the power transformed regional relationship. The formulae for the inverse power transformation are given by

$$(Q/Q_{mean}) = (W\lambda + 1)^{1/\lambda} \quad \text{when } \lambda \neq 0$$
$$(Q/Q_{mean}) = e^{W} \quad \text{when } \lambda = 0$$

A regional relationship for mean is developed correlating the mean flow with catchment area. The mean flow for any ungauged catchment can be estimated using the regional relationship for mean. The form of the regional model for mean is ,

$$Q_{mean} = CA^{m}$$

where A is catchment area in sq. km, Q_{mean} is the mean flow in cumec and C and m are the coefficients. The values of m, C and λ for different regions are given in the Table. The flow of desired dependability may be estimated for any ungauged catchment of the region by multiplying the mean flow with the non-dimensional flow of the respective dependability.

Region	States covered	M	C	Coefficient of Correlation (R)	λ
A	Jammu & Kashmir (Except Leh & Kargil)	0.06046	3.8189	0.0808	-0.241
B	Jammu & Kashmir (Leh & Kargil)	$Q/A = (1/2)[(Q/A)_{Leh} + (Q/A)_{Kargil}] = 0.05804$			-0.097
C	Himachal Pradesh	0.8611	0.1200	0.8759	-0.184
D	Uttar Pradesh	0.89075	0.0463	0.8174	0.131
E	Bihar	0.74795	0.0652	0.7742	-0.260
F	West Bengal and Sikkim	0.98920	0.0577	0.8467	-0.141
G	North Assam & Arunachal Pradesh	0.26817	2.2807	0.3706	0.230
H	South Assam & Meghalaya	0.48589	1.4136	0.6820	0.035
I	Manipur, Nagaland, Mizoram & Tripura	1.22343	0.0151	0.9435	0.138

ENVIRONMENTAL IMPACT

This technology envisages a numerical model development, which does not have any direct bearing on the environment. If some project is constructed based on the results of the model, then there would be some positive impact on the environment.

ECONOMICS

The technology will help in better estimates of water availability at various sites including ungauged sites in the regions under study. Therefore, by the use of this technology, fairly accurate estimates of power potential could be made based on the reliability of flow data at the gauging sites.

Application of this technology will prove to be cost effective and it will provide intangible benefits to the people residing in the area.

BENEFICIARIES

Organisations like state power corporations, national hydropower corporations, private hydropower corporations would be the main beneficiaries.

INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee, has the Intellectual Property Rights being the developer of the methodology.

IDENTIFICATION OF POLLUTION SOURCES IN GROUNDWATER

In the rising complexities of supply and demand of water, coupled with requirement of quality assurance, the pressure on groundwater has increased with the passage of time. Some of the definite reasons are: (i) groundwater is considered to be assured, and more risk free to pollution than surface sources of water; (ii) unsaturated zone filters the percolating water before it become spart of groundwater aquifer; and (iii) soil pores of saturated zone also play the role of filtration etc. However, the disadvantages with the groundwater aquifer are: (i) difficulties in decontamination, if it is contaminated; (ii) increasing human activities and their byproducts (changing land-uses and land cover) not only promote threat to the hydro-geological conditions of an aquifer, but also exaggerate spreading of toxic elements present in-situ in the groundwater domain. Some of the recent natural calamities in groundwater aquifer (Arsenic pollution, Fluoride activation etc.) in some parts of the country are cited examples. Prevention and cure of a disease is possible when the disease and its source is known. As decontamination of groundwater is a difficult task, or requires a gigantic cost involvement if a remedial plan is initiated, therefore, an accurate, reliable and cost effective method is essentially required to identify the source of contamination of water in an aquifer.

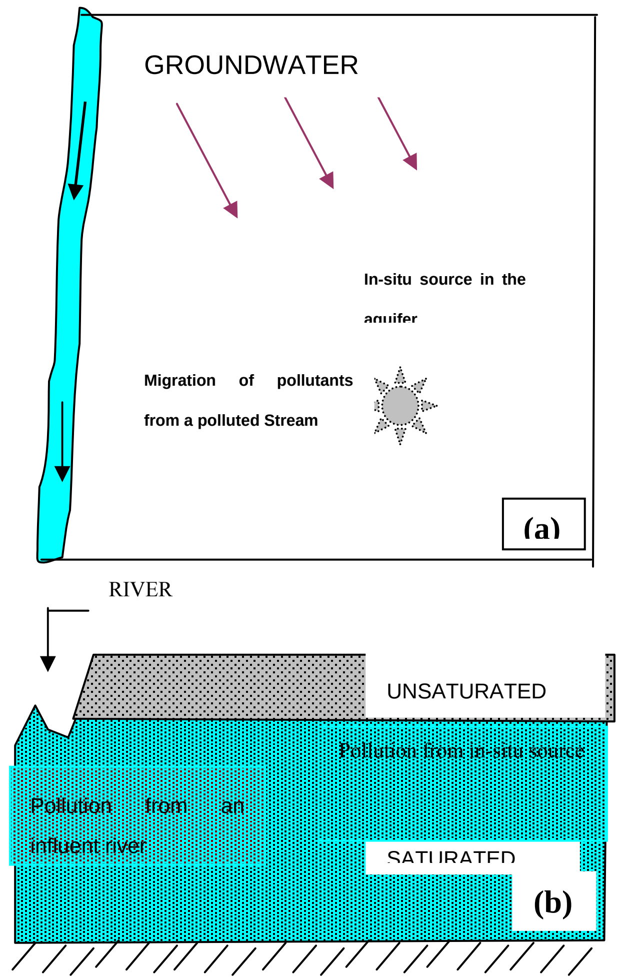


Figure-1: Schematic diagram showing unknown sources of pollution in a groundwater domain: (a) a plan view; (b) a cross-sectional view.

TECHNOLOGY

A source of Groundwater pollution is said to be a known source when it is apparently visible or can be detected with certainty. A source of pollution originating from overland, and contaminant leaching vertically downward to an aquifer can easily be detected. However, it is difficult to detect a hidden source (not apparently visible), which is triggered off because of exploitation of groundwater. Migration of pollutants from a polluting stream/river by the process of stream-aquifer interaction, activation and oxidation of in-situ toxic compounds due to the change of hydro-geological conditions etc are some examples of hidden sources of groundwater pollution (Fig. 1). For planning and developing an appropriate remedial measure the specific question before a planner and a decision-maker is; how can one detect a subsurface source, and what is its zone of influence? What are the cost-effective remedies? Definitely the answers would be scientific analysis.

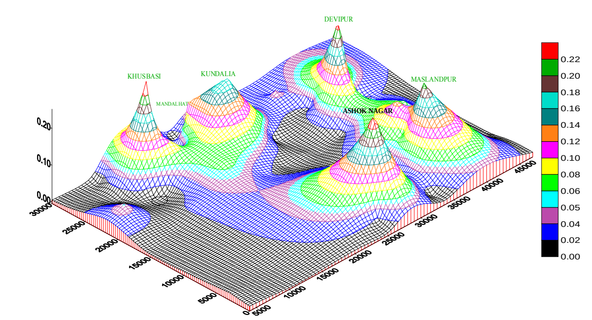


Figure 2 : Showing Arsenic contaminated zones (> 0.05 mg/l) in groundwater domain of a Arsenic affected area in West Bengal (Source is suspected

The groundwater flow velocity, hydrodynamic dispersion, sorption and kinetics of the organic matters besides other factors are primarily responsible for propagation and spreading of pollution source in a groundwater domain. Influence and dominance of these factors depend upon stress conditions (recharge and withdrawal rate), degree of heterogeneity of the aquifer material, nature of pollutants, soil types and soil textures etc. The larger the rates of recharge to ground water or the larger the withdrawal from groundwater, more is the spreading of pollution in a groundwater domain. When pollutants are in dissolved form they become part of the groundwater domain, and move with the flow of groundwater.

In a groundwater domain, pollutant moves along all three directions of flow i.e., major flow direction, transverse direction and vertical direction. Pollutant's transport mechanism in groundwater is well defined by 3-dimensional mathematical equation known as Advection-Diffusion equation. Numerical solutions to this equation for different real life flow conditions of pollutant transport are well documented in books. There are a number of source codes (models) available internationally derived using the above transport equation. Computational ease and scope of those models coupled with one's modeling skill have made identification of migration pathways of pollutant in a groundwater domain it easy with a good accuracy and certainty.

For identification of source of pollutant in a groundwater domain, a modeler has to develop an artificial domain of the prevailing hydrological and hydro-geological set up of the aquifer whose mathematical characteristics are representative of the physical processes of the actual aquifer through which pollutants move. Thereafter, simple tracking of movement of particle in a flowing media from known to unknown source or unknown to known source is done.

A primary requisite for tracking of movement of a particle in a groundwater domain is to know flow velocity along three-flow directions. The flow velocity changes due to the heterogeneity of the aquifer as well as the variation of stress conditions. Measurements of spatial and temporal variation of flow velocities are not only tedious but also a difficult task. Groundwater flow modeling is thus a prerequisite for pollution source identification and evolving a remedial strategy or for developing a well-head protection strategy or for delineating a risk free zone.

Expertise available at the Institute on pollutant transport modeling and associated areas has successfully been utilized for study of Arsenic pollution in groundwater in a selected patch of West Bengal in joint collaboration with Central Ground Water Board (CGWB).

ENVIRONMENTAL IMPACT

The methodology does not deal with any artificial injection of pollutants or implementation of a scheme but a tool for analysis and source identification in a groundwater domain already under the threat of pollution. Hence, there is no adverse impact on the environment.

ECONOMICS

Groundwater is the main source of water for different uses including drinking in many regions in the country. Safeguarding groundwater sources from any pollution hazards should be everybody's concern. The proposed package of scientific tools and analyses, if implemented, will bring out a direct benefit to the socio-economic and socio-cultural aspects of a region.

BENEFICIARIES

Central and State Ground Water Organisations, Pollution Control Boards and users of any scheme based on groundwater.

INTELLECTUAL PROPERTY RIGHTS

There is no element of intellectual property right in this technique.

MANAGING WATER LOGGING AND DRAINAGE CONGESTION

The term "Waterlogging" usually refers the condition of very shallow groundwater table causing affect on the growth and yield of crops. It is customarily linked with balance of the sub-soil water table and the soil pores in the crop root zone. Accumulation of surface runoff, and thereby stagnation of water over the depressed lands due to the restriction of natural passages of water which may arise because of inadequate surface drainage or due to the higher water level elevation at the out-falls also cause water-logging which is termed here as surface water-logging. In fact, there are hardly any separate definitions to define surface waterlogging. Waterlogging and drainage problems of such nature cause flooding of areas suitable for Kharif crops, resulting in loss of productivity. Stagnation of water for a longer period besides affecting agricultural activities of the area due to the rise of sub-soil water table also affects the socio-economic aspects of the region.

In the lower gangetic plains, because of the flat nature of the country, and large scale topographical abnormalities, and also due to the haphazard alignment of roads, railroads and canals, large area experience afflux of flood waters during rainy reason causing inundation and stagnation of water. On the right bank of the river Ganga in Central Bihar, a large areas locally known as "Mokama Tal area" has been reported to be experiencing the submergence of water every year particularly during the monsoon period occurring from June through September. The problems of surface water-logging and drainage congestion over depressed land of 1062 km^2 in Mokama tal area of Central Bihar are a long standing issue before the water resources planners in terms of management of such a complex problem, and loss incurring in achieving the requisite agricultural return. As such, one finds no reasons of not getting a scientific solution of the problem when it is looked in overall perspective of water resources management of basins contributing water to the Mokama Group of Tals with intention to manage the incoming flows over time and space.

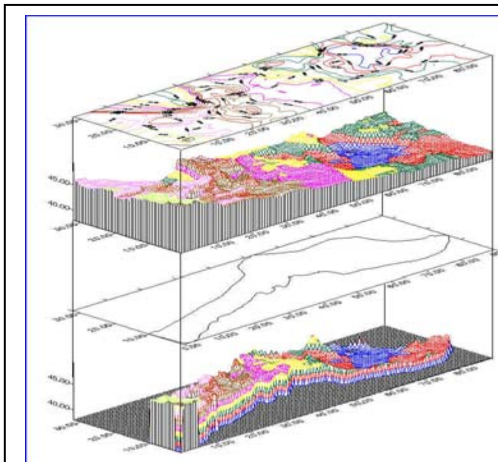


Figure 1: Digital Terrain Model (DTM) of Mokama Group of Tals

The methodology developed for this specific problem takes into account the total water balance of the basin and optimal allocation of water resources to suit various agricultural demands.

This methodology has a wide applicability in the areas suffering from surface water logging and drainage congestion problems.

TECHNOLOGY

Surface water logging in Mokama Group of Tals (Figure 1) is basically a problem of blockage of monsoon water runoff originating from the upper catchment and discharging to an area, which has a longer detention time to dispose off the incoming water. Alternately, the rate of inflow for a considerable period is much more than the rate of outflow, resulting in higher rate of storage of water in the vicinity. Towards solution of the problem, a management approach intending to check over inflows at the pace of need of water requirement for agriculture, and with no risk of water logging at the downstream considered to be the logical strategy.

The problem has been conceptualized as a management model considering that water logged area is acting as a storage reservoir whose drainage area is the total Kiul-Horahor basin, and during monsoon period the upstream runoffs are to be so regulated that storage does not create any danger of flooding rather would be able to meet the irrigation water requirement in the tal area and also at the upstream commands. Thus, a non-linear optimisation model is formulated taking into account the crop factors, the monthly reservoir storage values in the upstream catchment and the area expected to be exposed in the Tals.

The objective of minimising the waterlogged area in the monsoon season is equivalent to maximising the cropped area in the Tal. This is possible by minimising the inflow into the Tal, ensuring at the same time that the water stored in the Tal meets the crop water requirement of the catchment. Again, minimising the inflow into the Tal area is equivalent to maximising the water stored in the upstream reaches which is to be subsequently used for meeting the crop water requirements in the upstream reaches and the Tal area. The minimisation problem thus reduces and leads to maximisation of cropped area both in the upstream reaches as well as in the Tal area.

Most of the area in our country and specially Bihar is suffering from surface water logging problems. The technology developed for the management of water logging and drainage congestion problems of Mokama group of Tals can be implemented to other problematic areas suffering from waterlogging and drainage congestion problems.

ENVIRONMENTAL IMPACT

Utilisation of water in the uppper catchment of the Kiul-Harohar basin will improve landuse and forest and at the same time will reduce the surface waterlogging in the lower catchment. This will lead to a positive impact on overall environment of the river basin.

ECONOMICS

By restricting the incoming flows, the irrigation potential in the upstream catchment of kiul-harohar can be substantially increased. Similarly, this will have a direct impact on the reduction of surface water logged area in the mokama group of tals. The increased irrigation potential will have the positive boost in over all economic development of the area. Furthermore, the technology may be utilised to decide on the cropping pattern, which may provide maximum benefit to the farmers.

BENEFICIARIES

The direct beneficiaries of the technology include: Farmers of the region, State Water Resources Department and Local Administation.

INTELLECTUAL PROPERTY RIGHTS

The methodology and the software have been developed at National Institute of Hydrology, Roorkee, therefore, NIH has intellectual property rights of this technology.

NON-POINT SOURCE POLLUTION

Sources of pollution are broadly classified as either point or non-point sources. Point sources of pollution, as discrete identifiable locations, include municipal and industrial effluent and discharges from solid waste disposal sites among others. The most severe concentrations for point source pollutants carried in surface waters are during low-flow conditions.

On the other hand the non-point source pollution (*NSP*), as the result of intermittent releases of pollutants over large areas, is difficult to identify and measure directly. The relative importance and magnitude of the processes (i.e. hydrologic, physical and chemical), in determining non-point loads, will vary with land use categories and associated activities.

Estimation of non-point source (NPS) pollution is a topic of research that resulted in the development of numerous models and modeling techniques in the last few decades. Agricultural activities are an acknowledged non-point source (NPS) of pollution of surface and ground water.

It is very essential to estimate the area contributing non-point source pollutant discharge at different sampling points in a river. In India, very little work has been done to estimate non-point source pollution occurring due to agricultural practices and over-use of fertilizers during monsoon and non-monsoon periods.

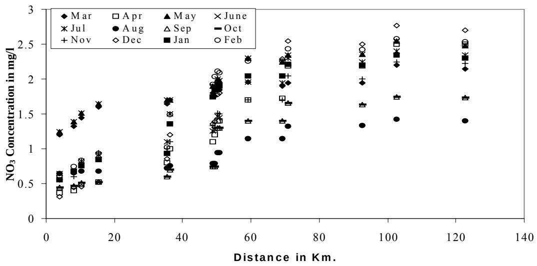
TECHNOLOGY

Non-point source pollution enters the receiving surface water diffusely at intermittent intervals. It may generate both conventional and toxic pollutants, just as point sources do. Although non-point sources may contribute many of the same kinds of pollutants, these pollutants are generated in different volumes, combinations, and concentrations. The extents of non-point source pollution are mainly related to infiltration and storage characteristics of the basin, the permeability of soils, geographic, geological, land use/land cover conditions differing greatly in space and other hydrological parameters. The important waste constituent outflows from diffuse sources are suspended solids, nutrients and pesticides.

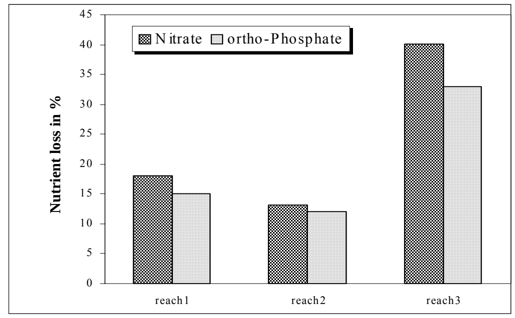
Non-point loads have been often related to basin characteristics, incident rainfall, applied fertilizer doses and prevailing cropping pattern in the areas. With the help of emerging techniques, a variety of basin characteristics such as land use / land cover, area under different crops, digital elevation model, slope, aspect map showing flow direction can be assessed. In addition, the information pertaining to fertilizer doses may be collected through public interaction and the available statistics at concerned authorities.

Numerous studies have been conducted globally since early seventies to understand the processes controlling non-point source pollutants in the river systems. Several researchers have estimated export coefficients and used different equations to compute the contribution of different water quality constituents from the watershed during monsoon period. Modelling approaches have been attempted at the institute to predict non-point source pollution during monsoon and non-monsoon period. The models are based on chemical mass balance approach, reaction kinetics and mass balance differential loading approach. Considering that non-point pollutants may also go under a process of attenuation due to a variety of mechanisms including settling, disintegration / decay due to reaction, a modification to the mass balance equation is proposed. It has been found that mass balance differential loading approach considering the non-point load under the assumption of uniform distribution along the stream reach is found to perform consistently better. The results obtained using this approach minimizes error estimates and improves correlation between observed and computed non-point source loads. However, other approach may also be used with fairly good estimate of non-point source pollution.

Estimation of non-point source pollution (*NSP*) load in rivers from the surrounding agricultural area is of utmost importance due to enhanced application of fertilizers and chemicals for intensified agriculture production from agricultural area. During monsoon period if agricultural chemicals are placed on the land surface and overland flow is generated by a storm, a significant amount of non point source pollutants/contaminants can be lost into surface waters. During non-monsoon period the non-point source pollutants are transported through sub-surface flow and overland flow from areas very close to the banks of the river. Therefore, it is very essential to estimate the area contributing non-point source pollutant discharge at different sampling points in a river.



Nitrate concentration



Nutrient loss

ENVIRONMENTAL IMPACT

The developed technology shall improve the environment.

ECONOMICS

It will have non-tangible and indirect benefits.

BENEFICIARIES

Central and state government agencies (Central Pollution Control Board, Central Water Commission, State Pollution Control Board, State Water Resources Department) and non-governmental organisations.

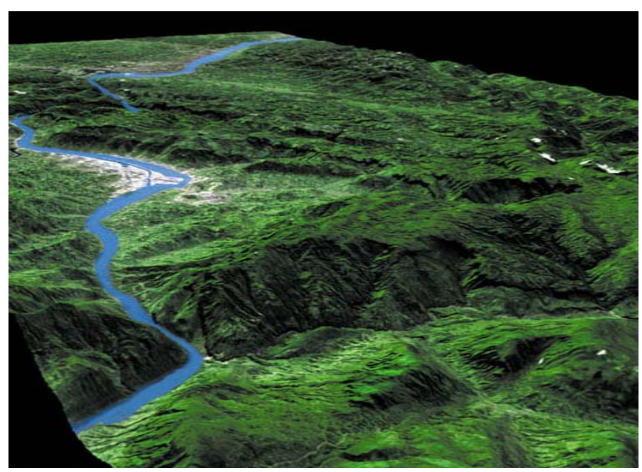
INTELLECTUAL PROPERTY RIGHTS

There is no such element involved.

PREDICTIONS IN UNGAUGED BASINS

Estimation of design flood, flood recurrences, risk involved in design flood and corresponding confidence levels are the information that are needed for river basin planning, water availability studies, design of highway culverts, railway bridges, water harvesting structures, bridges, road embankments etc. For many catchments, the stream flow data are limited, and for many catchments, these are not available. Under such circumstances regional/ empirical formula are developed using the data of gauged catchments in the region and are used to arrive at design flood for the ungauged catchment. In developing country like India, since most of the basins are ungauged due to lack of instrumentation network, inaccessibility reasons, monitoring difficulties, the need for such studies is still greater. Design of small projects, which require design return period flood, unit hydrograph and water availability analysis, gets delayed because of lack of data or of standard procedures. Further, the existing regional formulae for estimation of such design parameters (if exist), need to be updated and standardized with latest available data and methods.

In India, regional flood studies have been carried out using conventional methods. For some typical regions attempts have been made to study application of the new approaches in the studies conducted at some of the Indian research institutions and academic organizations.



TECHNOLOGY

Two methods have been developed to determine synthetic hydrographs. Here the term *synthetic* denotes that the flow generating from certain rainfall amount can be calculated in a basin without using watershed's rainfall-runoff (flow) data.

Most of the existing synthetic unit hydrograph methods involve manual, subjective fitting of a hydrograph through few data points. Because it is difficult, the generated unit hydrograph is often left unadjusted for unit runoff volume. To circumvent this problem, two simplified versions of the existing two-parameter Gamma and Beta distribution are introduced to derive a synthetic hydrograph more conveniently and accurately than the popular methods.

Another technique to develop a regional flood formula using regression approach can also be used. This formula can be employed to estimate the maximum flood that a basin shall generate in a required span of time (also known as return period flood). The region consisted of 100 Indian catchments (including 14 catchments of North Eastern parts of India) ranging from 25.1 to 19526 km^2 and with record length of 10 to 36 years. The model was calibrated for a variety of situations, and on the basis of detailed investigations, the use of present model was advocated to compute return period flood at an outlet of any specific catchment where no flood or limited flood records were available.

ENVIRONMENTAL IMPACT

It does not have any adverse impact on the environment.

ECONOMICS

It will have intangible benefits.

BENEFICIARIES

The beneficiaries from this work include various government organizations, such as the Central Water Commission, Irrigation Departments, Research Design and Standard Organization (Ministry of Railway), Soil Conservation Departments, Forest Departments, and Rural Welfare Departments.

INTELLECTUAL PROPERTY RIGHTS

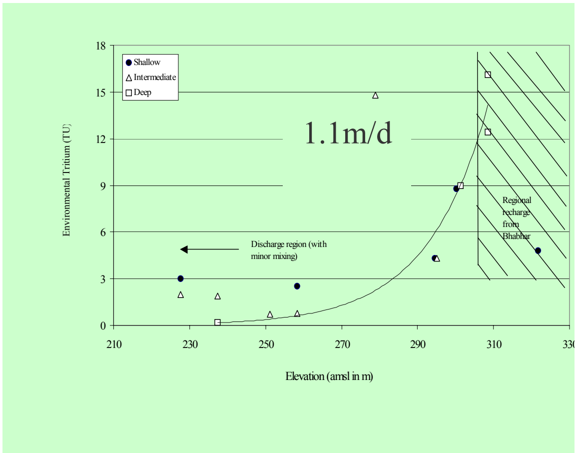
No intellectual property rights issues are involved in this technology.

RECHARGE ZONES AND SOURCES TO AQUIFERS

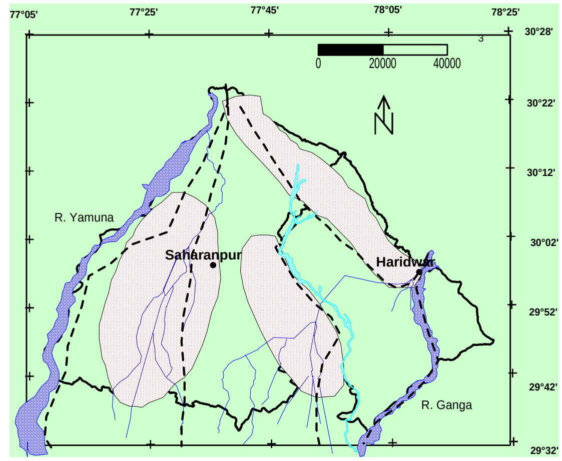
Groundwater forms the 85-90% of potable water as it is believed to be safe, free from pathogenic bacteria and from suspended matter. However, the deeper aquifers are becoming increasingly important with the increase in urban area and density of urban population. The area of groundwater recharge varies inversely with the density of urbanisation in urban areas. Thus the shallow aquifers are either drying -up or being contaminated in densely urbanized areas in the country. This leads to more dependency on deeper aquifers which have not been given due importance so far from investigation point of view. Our most of the observations and investigations are limited to the shallow aquifers. Thus, the deeper aquifers for which recharge zones are located in remote areas or areas quite away from the area of utilization, may suffer adversely by the various anthropological activities, that may either reduce the recharge area or contaminate the recharge source. It has increased the concern on groundwater resource mapping and its management that requires the identification of recharge-zones to deeper aquifers. In fact, the deeper aquifers not only cater to the maximum need of fresh water at present but these will also be the potential source of fresh water in future when the shallow aquifers will either be dried up or contaminated in densely populated areas and metropolitan cities. Once the recharge zones are identified, these can be protected from the anthropogenic activities and the most important recharge source can be given due importance for its better management.

TECHNOLOGY

Environmental isotopes like ^{3}H(tritium-3), ^{14}C(carbon-14), ^{2}H(deuterium-D), and ^{18}O(oxygen-18) are used to identify the recharge zones and recharge sources to deeper aquifers. Geohydrological details like groundwater level conditions, geological cross sections etc., and water quality data like major and minor ion chemistry, physico-chemical parameters etc., are used as supporting tools. Groundwater samples are collected from different aquifers for the measurement of ^{3}H, ^{14}C, ^{2}H, and ^{18}O. The dating of groundwater using tritium and carbon-14 provides the age of groundwater and the special distribution of it provides information of recharge zones, groundwater flow velocity and flow pattern. The D and O-18 (δD and $\delta^{18}O$) analyses help in understanding the contribution of different recharge sources and also help in concluding the most important recharge source.



Variation of environmental tritium with elevation in Solani-Ganga Interfluve



Map showing different recharge zones identified on the basis of environmental tritium concentrations.

The geohydrology and water chemistry are used as supporting tools. The use of this technology has been established in india by the institute and applied in districts Haridwar and Saharanpur while it is being applied in NCT of Delhi and the area between Hindon and Yamuna Rivers.

ENVIRONMENTAL IMPACT

As this technology involves the use of environmental isotopes (natural level activity), therefore, it does not have any adverse effect on environment.

ECONOMICS

An expenditure of Rs. 1.0 lakh per 100 sq km area is required for sample collection, measurements and interpretation excluding travel cost. The measurements can be done either at NIH Roorkee or other isotope hydrology laboratories in the country, therefore, the cost of instrumentation is not indicated.

This technology will have longterm impact in terms of availability of groundwater in deeper aquifers, measures to control groundwater contamination and in preparing strategies for groundwater management. Thus, it will have direct and indirect benefits that may not be spelled out in digits.

BENEFICIARIES

All state and central ground water organisations, individual exploiters of groundwater, municipal boards, jal nigams, Jal sansthans, and tube-well corporations will benefit from this technology.

INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee has the rights of intellectual property for the technology established in India.

RESERVOIR OPERATION

Reservoirs are one of the most important components of Water Resources Development. In India nearly 4000 major and medium reservoirs have been developed for utilization of river flows. India has a monsoon climate in which about 85 to 90% of the annual flow takes place during four months of monsoon. In view of this, it is necessary to store water when its availability far exceeds the demand so that the requirements during dry season can be met. During the recent times, construction of new projects is becoming increasingly difficult since the availability of suitable sites is becoming less, there are environmental and resettlement issues which are an obstruction to new projects because of financial reasons. However, the demands for water for various uses are increasing and every year some available storage capacity is loss due to sedimentation. In view of these reasons, it is important that the existing reservoirs are operated in the most efficient manner.

TECHNOLOGY

A software package named Software for Reservoir Analysis (SRA) has been developed at NIH that contains modules for specific analysis. The main modules include storage yield analysis, hydropower analysis, reservoir routing, and simulation of a multi-reservoir system for conservation operation and for flood control operation. The package is menu driven so that a user who is not skilled in computer usage can easily use it. The analytical procedures are those that are followed in field organizations and results are presented in a form that can be readily used by field engineers. In addition to tabular output, graphs are also generated for easier visualization.

Studies have shown that improvement in operation of reservoirs, by a few percentage points, translates into large sum of money. The SRA software is being used by field organizations such as Central Water Commission, National Water Development Agency, Central Design Organizations of a few states, Narmada Control Authority, etc. It is also being used in academic organizations such as IIT, Chennai and IIT Roorkee as a teaching aid. Wider use of such indigenously used software will definitely help in better management of water resources of India, higher economic benefits, poverty alleviations and improvement of environment.

This software has been developed, validated and used at NIH for a number of reservoirs analysis.

ENVIRONMENTAL IMPACT

It does not involve any adverse impact on the environment.

ECONOMICS

It will have intangible benefits.

BENEFICIARIES

The beneficiaries from this work include various government organizations, such as the Central Water Commission, Irrigation Departments, Research Design and Standard Organization (Ministry of Railway), Soil Conservation Departments, Forest Departments, and Rural Welfare Departments.

INTELLECTUAL PROPERTY RIGHTS

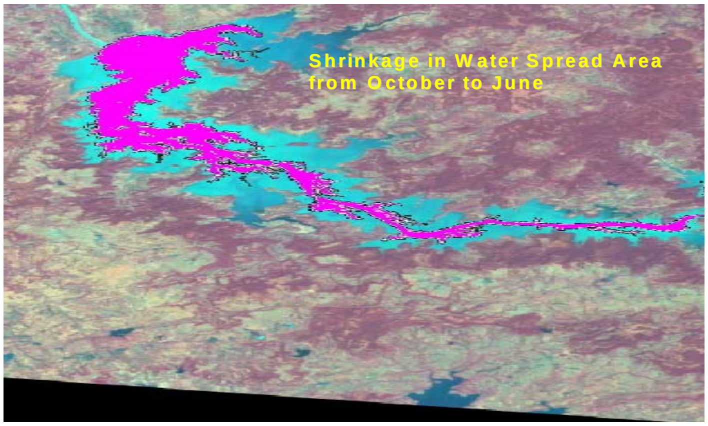
Since the software has been developed at NIH, the intellectual property rights in respect of the software wholly lies with NIH.

RESERVOIR SEDIMENTATION

During the last five decades, India has constructed nearly 4000 major and medium river valley projects involving construction of dams and creation of reservoirs for flood control, irrigation and hydropower. Due to soil erosion in the catchment areas and its transport and deposition, the reservoirs are losing their storage capacity with time. To determine the useful life of a reservoir, it is essential to periodically assess the sedimentation rate. In addition, knowledge about the sediment deposition pattern in various zones of a reservoir is essential for proper allocation and management of water in a reservoir. With the up-to-date knowledge of the sedimentation process going on in the reservoir, timely remedial measures can be undertaken and reservoir operation schedules can be planned for optimum water utilization. Systematic capacity surveys of a reservoir are conducted periodically to estimate the rate of sedimentation. The conventional techniques of sedimentation quantification in a reservoir, like the hydrographic surveys and inflow-outflow methods, are cumbersome, costly and time consuming. Further, prediction of sediment deposition profiles using empirical and numerical methods requires large amount of data and still the results may not be accurate.

TECHNOLOGY

Remote sensing technology, through its spatial, spectral and temporal attributes, can provide synoptic, repetitive and timely information regarding the current water spread area in a reservoir. By using the digital analysis techniques and the geographic information system in conjunction, the temporal change in waterspread area is analysed to evaluate the sediment deposition pattern.



A digital interpretation technique of the satellite data has been developed at NIH to identify the water pixels. Although spectral signatures of water are quite distinct from other land features such as vegetation, built-up area and soil surface, yet, identification of water pixels at the water/soil interface is very difficult and depends on the interpretative ability of the analyst. To overcome this problem, a mathematical algorithm has been developed for identifying the water pixels using the data of different bands. The algorithm checks for following condition for each pixel. If the condition is satisfied, then it is recorded as water, otherwise not:

"If the radiance value of near-IR band (B3) of a pixel is less than the radiance value of the red band (B2) and the green band (B1), and the normalized difference water index is less than some value then it is classified as water otherwise non-water".

The reduction in reservoir capacity between consecutive contour levels is computed using the prismoidal formula. The overall reduction in capacity between the lowest and the highest observed water levels can be obtained by adding the reduced capacity at all levels.

Using remote sensing technique, a number of case studies of reservoir sedimentation assessment have been carried out at NIH. The reservoirs that have been studied include Ukai, Bhakra, Dharoi, Ramganga, Tandula, Somasila, Bargi, Ghatprabha and Lingnamakki reservoirs.

ENVIRONMENTAL IMPACT

It does not involve any adverse impact on the environment.

ECONOMICS

It will have tangible and intangible benefits.

BENEFICIARIES

Capacity estimation by remote sensing technique at regular time interval can give important information like annual rate of sedimentation and sediment deposition pattern in the reservoir area. The beneficiaries of the studies will be dam operating authorities, water resources planners, hydropower organizations, and state irrigation departments.

INTELLECTUAL PROPERTY RIGHTS

No IPR issues are involved in this technology.

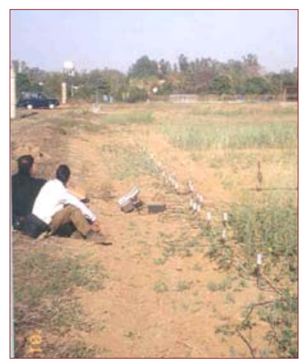
RESISTIVITY METHOD FOR ESTIMATING GROUNDWATER RECHARGE

Watershed management and Command Area Development (CAD) programmes rely on the improvement of soil moisture regime and enhancement of infiltration in the watersheds. The study of movement of water and solutes through the soil attains special significance in the context of human interference in the soil-atmosphere ecosystem.

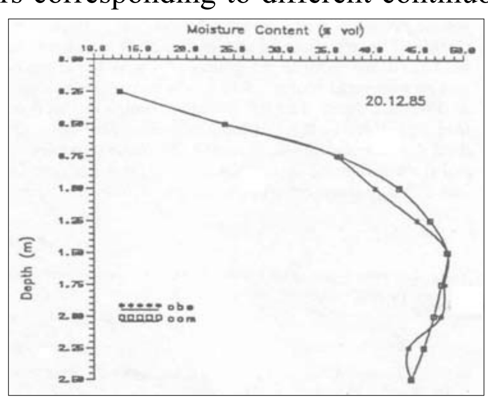
For effective monitoring of groundwater recharge under in-situ conditions, regular monitoring and periodic appraisal of the data from the watersheds is crucial. This requires a technique which (1) has quick response to the water variation in the subsurface, and (2) is able to monitor the data regularly and, at the same time, is least destructive to the site. These objectives can be met by an automated resistivity measurement setup capable of regular monitoring of subsurface water movement, and its variation with depth and time.

TECHNOLOGY

A procedure for estimation of in-situ groundwater recharge using periodic resistivity sounding measurements has been developed. The technique being based on potential measurements of fairly large volume of subsurface soils, provides results representative of a region rather than a point value. In the resistivity sounding method, a constant current is injected into the ground through two metal electrodes for a certain time and, then, potential difference between another set of two metal electrodes is measured.



The moisture profile in the unsaturated zone can be represented as a 1-D model in situations where the movement of infiltrated water is dominantly vertical. Such a continuous profile can be analyzed using a stratified earth model, with different layers corresponding to different continuous segments of the moisture profile. The estimation of the moisture variation in a soil profile from the apparent resistivity measurement is essentially an inverse problem. The whole exercise may be viewed as a two-step process; first the resistivity variation with depth is determined



after interpreting the apparent resistivity data, and then moisture content is estimated from this resistivity variation using a moisture-resistivity calibration equation.

Steps Involved

- Interpret apparent resistivity data in terms of layer parameters (i.e. layer resistivity and thickness)
- Convert layer resistivity into soil moisture content using calibration equation
- Instant soil moisture profile is obtained
- Repeat above steps to determine temporal variation in soil moisture content
- Estimate groundwater recharge by determining moisture variation in the soil profile at different time instants.

With this technique, the movement of soil moisture with depth can be monitored using resistivity data alone. The developed technique was used to estimate the soil moisture profile at a site in Roorkee (Uttaranchal) using resistivity sounding data. The estimated values were compared with the observed values, and the error was found less than 10% in all the cases.

ENVIRONMENTAL IMPACT

Since the resistivity technique does not require any digging of holes for measurements, it provides a non-destructive alternative to the conventional techniques. The technology has no adverse environmental impact.

ECONOMICS

Use of the technique for groundwater recharge estimation would require a resistivity meter, which requires a one-time investment of about Rs. 2-3 lakh. This instrument setup can then be used to cover a vast area for periodic measurements (e.g., at fortnightly or monthly intervals). A recurring expenditure of Rs. 200 per day/site approx. would be required to cover the expenses related to field observations and data processing, etc. However, the information gathered by this technique is of utmost importance for understanding the behavior of unsaturated zone and recharge to groundwater . Thus it will have tangible and intangible benefits.

BENEFICIARIES

The main beneficiaries of the developed technique would be CAD departments and other organizations interested in groundwater recharge.

INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee has the Intellectual Property Rights being the developer of the methodology.

SIMULATED FLOWS IN HIMALAYAN RIVERS

In the Himalayan basins, precipitation falling as snow during winter period accumulates in the basin and snow pack is developed. Depending upon the climatic conditions, the snow pack depletes either fully or partially during the forthcoming summer season. Because of variation in climatic conditions and changes in the aerial extent of snow-covered area with time, the contributions from the rain and snow to the streamflow vary with season. Streamflow gets higher share from snowmelt during spring and summer. The contribution from rain dominates in the lower part of the basins (altitude < 2000 m). The middle and upper parts of the basins (altitude > 2000 m) have contribution from both rain and snowmelt and their contribution changes with altitude. As the elevation of the basin increases, rain contribution to streamflow reduces but snow melt contribution increases. After depletion of seasonal snow, melt runoff is generated from the glaciers. Runoff is dominated by the snowmelt runoff and glacier melt runoff above 3000 m altitude. Different components of runoff make these rivers perennial in nature.

The annual water yield from a high Himalayan basin is roughly double than that of an equivalent size basin located in the Peninsular part of India. A higher water yield from the Himalayan basins is mainly due to the large water inputs from the melting of snow and glaciers. Himalayan basins have very high potential of hydropower generation due to its topographical setting and available water resources, particularly in the form of snow and glaciers. A number of hydropower projects exist and are being proposed at the potential sites of the Himalayan rivers.

The streamflow of Himalayan rivers is integrated runoff generated from different sources. The process of generation of streamflow from such basins involves primarily the determination of the input derived from snowmelt and rain, and its transformation into runoff. NIH has developed a conceptual snowmelt model (SNOWMOD) for simulating the streamflow of snowfed rivers.

TECHNOLOGY

The conceptual snowmelt model (SNOWMOD) is designed to simulate daily streamflow its components (rainfall, snow melt and baseflow) for the mountainous basins having contribution from both snow melt and rainfall. The model is designed primarily for the snowfed basins and conceptualises the basin as a number of elevation zones depending upon the topographic relief of the mountainous basin. Various hydrologic processes relevant to snow melt and rainfall runoff are evaluated for each zone. Keeping in view the poor availability of meteorological data in the high altitude region of Himalayan basins, precipitation, temperature and snow cover area data are used as inputs to the model. Temperature index or degree-day approach has been used to compute the snow melt in the basin and heat content supplied by the rain is also incorporated. A part of the rainfall and snow melt contributes to the direct surface runoff. The remaining water contributes to soil moisture of the unsaturated zone. As soon as the soil moisture content reaches to the field capacity, additional infiltrated water contributes to the groundwater storage as ground water recharge. The groundwater contributes to streamflow in the form of baseflow with much delayed response. A part of the soil moisture is depleted because of evapotranspiration. The routing of surface runoff components is carried out separately for snow covered area and snow free area because their hydrological response is different and also the extent of each of them varies with time. Three components together constitute the total runoff from the basin. The model has been calibrated and validated for few Himalayan basins. The structure of the model is given in Figure 1.

The ability of the model to simulate snow melt runoff and rainfall runoff separately enabled to estimate the contribution of each component to the seasonal and annual total streamflows. The model can be applied to estimate the contribution from snow melt and rainfall into seasonal and annual flows.

ENVIRONMENTAL IMPACT

It will not have any adverse effect on the environment.

ECONOMICS

The model can be used to estimate water availability at the potential sites for small, medium and large multipurpose projects. In case those projects are completed, it will provide the tangible and intangible benefits. A better planning and utilization of available water resources would improve the economy of the region/country.

BENEFICIARIES

All organizations dealing with hydropower, irrigation and development, planning and management of water resources in the Himalayan region, will be benefited by such studies. Beneficiaries include Bhakra Beas Management Board (BBMB), Electricity Boards, Public Health and Irrigations Departments of the States like, Jammu and Kashmir, Himachal Pradesh and Uttaranchal etc.

INTELLECTUAL PROPERTY RIGHTS

The methodology and the software for the technology have been developed at by the National Institute of Hydrology, Roorkee, therefore, NIH has intellectual property rights over this technology.

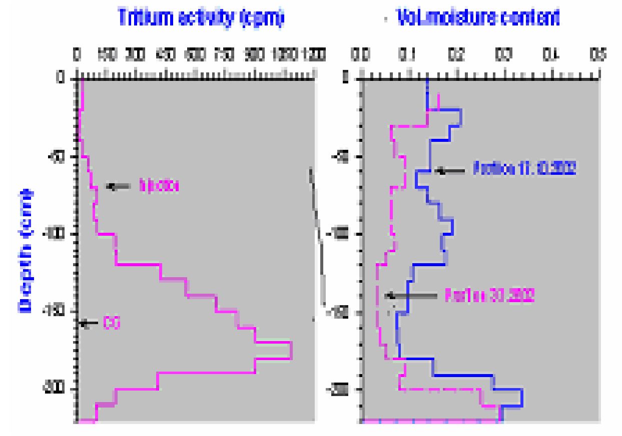
VERTICAL COMPONENT OF GROUNDWATER RECHARGE

Estimation of recharge to groundwater is essential for evaluation of groundwater resources. In most of the cases, major source of recharge to groundwater is precipitation. However, in the irrigated areas the return seepage also contributes to groundwater recharge significantly. As the recharge to groundwater is the most important parameter for water balance study of a water resources project, it should therefore, be estimated very correctly otherwise it may lead to a great deal of miss calculations in the planning of water resources projects. Tritium Tagging Technique is used to estimate the recharge to groundwater more accurately than other conventional methods. This technique can also be used to map the potential areas for groundwater recharge in a watershed/catchment that could be used for implementation of artificial recharge measures in the areas that are facing groundwater scarcity problem. On the basis of experimental data, mathematical relations can be developed between rainfall and recharge at regional scale that can be used to compute recharge with respect to rainfall in future.

TECHNOLOGY

Tritium Tagging Technique is used to estimate vertical component of recharge to groundwater in a selected area due to rainfall and irrigation. In this technique, if the rechage due to monsoon rains is to be determined, then tritium of very small quantity (2 ml) and specific activity (40 μCi) is injected in a number of holes at a depth of 70 – 100 cm at a selected site before the onset of monsoon rains (for estimating irrigation return flow, the injection can be made according to the season and crop at the selected field site) and the soils samples are collected from the pre marked points after the monsoon is over. The volumetric moisture content of each soil sample is estimated in the laboratory and the soil samples are subjected to distillation in the laboratory. The tritium activity of the each distilled sample is measured in the laboratory using normal liquid scintillation counter. Knowing the peak shift of the tritium and average volumetric moisture content in the peak shift region the amount of recharge to groundwater can be estimated by multiplying peak shift and average volumetric moisture content in the peak shift region at each site. Further, mathematical approach can be followed to develop empirical relations on regional scale that can be used to compute recharge to groundwater due to rainfall in that region in future.

A view of Tritium Injection



Tritium and soil moisture profiles

The institute has successfully implemented this technology in parts of Ganga Yamuna doab, Naramada basin, Bundelkhand region of U.P. state, and alluvial areas of Maharashtra.

As an example, the brief details of study carried out in Bundelkhand region are given here. The Bundelkhand region in India comprises 12 districts out of which 5 fall in Uttar Pradesh and 7 fall in Madhya Pradesh. The study area comprises four districts, namely Jalaun, Banda, Hamirpur and Jhansi, covering an area of approximately 24079 km^2. Bundelkhand region of India falls in subtropical region characterized by hot and prolonged summer followed by rainy season and cold winter. The distribution of rainfall is not only erratic in the region but the same situation persists even in a small area, causing occasional drought conditions. District Jalaun, Banda and parts of Hamirpur (60%) and Jhansi (10%) are underlain by indo-gangetic marginal alluvium of quaternary age and comprise mainly of sands of various grades, clay and clay mixed with kankar while the major parts of district Jhansi and about 40% area of district Hamirpur fall under rocky formation. Ttherefore, the surface soil in Hamirpur is more compact in comparison to that of the other two districts.

Bundelkhand region in India faces acute water deficiency due to higher losses of rain and surface waters. Although, the rainfall in this region is less in comparison to the surrounding region but it is much higher in comparison to the rainfall in semi arid regions. The groundwater reserves have been found very limited and groundwater level is also deep at number of places. Hence, it is treated as an undeclared semi-arid region in India.

Tritium was injected at 25 sites before the start of monsoon rains. Soil samples were collected from the injected sites in the month of November and recharge percentages were determined. Since, sampling was carried out in November, the water input for the irrigation was also taken into account while determining the recharge percentage.

Mathematical Approach

Groundwater recharge by rainfall is a very complex process influenced by numerous surface and sub surface parameters including rainfall intensity, its frequency and several other local factors (e.g. vegetation cover, soil properties, etc.). Therefore, it is advisable that once, the recharge to groundwater due to rains and/or irrigation is determined using tritium tagging technique, a partly suitable mathematical approach can be developed which will be accounting for all the known and unknown factors affecting the rainfall-recharge process. However, it is not necessary to follow only this procedure, therefore, if the correct information of all the processes and parameters which affect the rainfall- recharge process are possible to obtain, a suitable mathematical model can be developed.

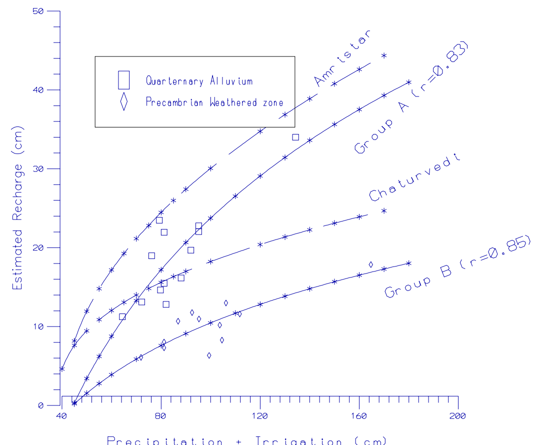


Fig. 2

It has been observed that the recharge values follow a unique logarithmic relationship with rainfall, for similar site conditions, while different relations are observed for the other set of sites. The following two mathematical formulations fairly satisfy the variation of recharge values.

Group A	$Rg = 29.316 \ln(P) - 111.259$	$(r = 0.83)$	(1)
Group B	$Rg = 12.861 \ln(P) - 48.757$	$(r = 0.85)$	(2)

Where Rg - is recharge to groundwater in cm and P - is rainfall/precipitation in cm.

It was observed that recharge values for the sites which fall in the marginal alluvium region follow equation (1) while those which fall in the hard rock region follow equation (2).

ENVIRONMENTAL IMPACT

A hazardous radioisotope i.e. tritium is used in this technique, but there is no adverse effect of this radioisotope on environment as such as the activity of tritium used is very less.

ECONOMICS

The expenditure for collection of samples will be Rs.1000.00 per site per 10 sq km excluding traveling charges. As the measurement of tritium activity can be done either at NIH, Roorkee or at other isotope laboratories available in the country at a nominal cost, therefore, the cost of instrumentation is not included here. This technology has longterm benefits, both direct as well as indirect.

BENEFICIARIES

Central and state ground water organisations and other agencies that are responsible for evaluation and development of groundwater resources in the country. R & D organisations that are working in the area of water resources research.

INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee has the rights of intellectual property for the second part of this technology.

WATER MANAGEMENT IN IRRIGATION COMMAND

Irrigation is required to obtain high crop yields through optimum scheduling of water application on farms. Both, the quantity and timing depend upon various meteorological factors and the soil water status for any given crop. For maximizing the crop yield, there is a need to carefully plan the regime of watering over the entire crop period. Introduction of canal irrigation facilities in a command area sets new hydrological regime in the area with revised conditions of groundwater recharge and withdrawal. If the water is not utilized as per the developed plan, an imbalance is created in the ecosystem that can lead to further deterioration of the system. Because of the indiscipline in the irrigation water distribution, excess water is used in the head reach of the command area with a belief that more the water supplied to the crop, the higher would be the yield. Excess irrigation causes water-logging due to rise in the subsoil water table. Continued water-logging results in salinity development and may render the land unproductive. Further, due to irregularities in the irrigation water distribution, the tail end of a command area is deprived of irrigation facilities leading to complaints and discontent.

Different methods of water distribution are followed in canal irrigation systems in India. The Warabandi system of Haryana, Punjab and Rajasthan (also known as Osrabandi in Uttar Pradesh) is a system of delivery of water in rotation amongst cultivators sharing water from a canal outlet. The share of water of an irrigator is in proportion to the area of his landholding in the command outlet. The Shejpali and Block system of western and central India is a demand based water distribution system operated in the States of Gujarat, Maharashtra, Karnataka and parts of M.P. Under this system, estimates of expected water availability are made and applications are invited from farmers seeking information on the crop to be grown and the area to be irrigated under each crop. Sanctions are provided to farmers by the State Irrigation Department to grow particular crops and the farmer is thus authorized to draw water to suit his perceived needs. In the Zonal System, introduced in the Lower Bhavani Project in Tamil Nadu, the command area is divided into two halves. Water is made available continuously to one half of the area for one season. The other half gets irrigation water sufficient for wet crops in the next year. This way each half gets irrigation supplies for wet and dry crops in alternate years. Localized System is practiced in most of the irrigation projects in southern and north-eastern states as well as in the states of West Bengal, Orissa, Bihar and Jammu and

Kashmir, where paddy is the main crop. Under this system, irrigation proceeds from one field to another through surface flooding.

The importance of conjunctive management has long been felt in India. Further, the decision-making process for irrigation management in this country is handicapped with the non-availability of geographic information on real-time basis and the inability to process and analyze vast quantity of geographic data. With the advent of satellite remote sensing, it has now become possible to gather and update information of large areas at regular intervals. Using a (GIS), the spatial information can be efficiently stored, analyzed and retrieved.

A number of canal operation simulation models have been developed in the past and discussed in several ICID/FAO publications and Technical Journals. However, there was a need to develop a comprehensive tool (geo-simulation model) that can integrate various processes of irrigation management from micro-scale (field level) to macro-scale (canal system). The tool must be capable of integrating the real-time information coming from remote sensing observations and the spatial details provided by the GIS to help the irrigation managers in analyzing the system operation under current state of the system and analyze various decision alternatives. Recognizing the need of such a tool and importance of conjunctive management of irrigation commands in a judicious and scientific manner in this country, a model [Simulation of Integrated Network of channels for Irrigation (*SINCHAI*)] has been developed.

TECHNOLOGY

SINCHAI integrates the information about the actual irrigation demands in the command area, available surface water, canal system details, and the groundwater scenario in the command area and suggests a possible plan of operation of the canal system at weekly time step. The model uses the remote sensing observations for ascertaining the cropping pattern in the command and is linked to GIS database for utilizing the spatially distributed data of different variables (rainfall, soil type, crop type, groundwater conditions etc). By optimally using the canal water and groundwater, it is possible to keep the groundwater conditions in the command within the desirable range while simultaneously spending least amount of power for groundwater extraction.

SINCHAI consists of two major distributed models [Soil Water Balance Model (SWBM) and Canal Network Simulation Model (CNSM)] and a number of sub-models for database generation and linkage. The purpose of SWBM is to simulate the moisture variation in root zone of crops for finding spatially distributed irrigation demands, groundwater recharge, water stress conditions in crops, and soil moisture content at the end of each week. Figure-1 shows the irrigation demands in a command in a particular week.

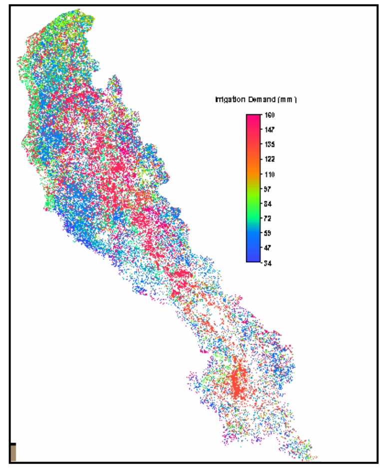


Figure – 1 Irrigation demand map

CNSM is used to analyze various scenarios of canal network operation on the basis of water demands, supply, and system characteristics. For generating revised groundwater conditions corresponding to different canal operation scenarios, an existing groundwater simulation model (Visual MODFLOW) is linked to SINCHAI. Figure – 2 shows the canal operation plan corresponding to the irrigation demands, canal water availability, and a specified policy of operation.

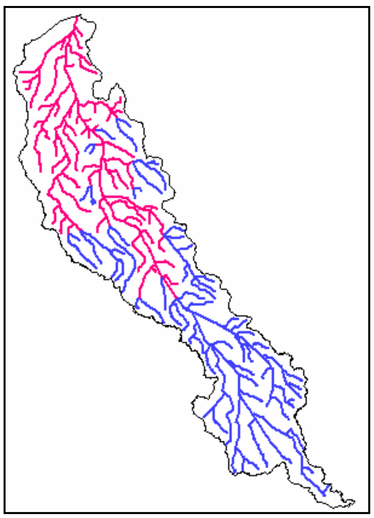


Figure – 2 Canal operation map

To analyze the performance and utilisation of SINCHAI, it is applied to Lakhaoti branch canal command (with a gross area of about 1956 sq. km) under the Madhya Ganga Canal System in U.P. State, India. Application of the model is demonstrated for one crop season of a particular year. It is found that under assumed scarcity conditions in one crop season, considerable amount of electricity can be saved under similar conditions of water supply to existing crops by judiciously operating the canal system. Maps corresponding to irrigation demands, groundwater recharge, water stress conditions in crops, various canal operation details, such as discharge and run-time etc. and performance indicators can be prepared with SINCHAI.

ECONOMICS

To apply the developed model in an irrigation command, major expenditure is incurred in the procurement of remote sensing data for cropping pattern determination and canal layout mapping, and digitisation of different data layers in GIS. An image of remote sensing costs approx.

about Rs.20000/- and covers an area of 19600 sq. km. Depending on the coverage of the area in one scene and the number of scenes required on different dates, the cost of remote sensing data can be worked out.

ENVIRONMENTAL IMPACT

The model tries to equalize the groundwater conditions in the command area. Withdrawal of groundwater from the water-logged area helps in reclaiming the submerged land while recharge of water (as canal seepage) in the deep groundwater zones helps build-up the water table. Therefore, it will have tangible as well as intangible benefits.

INTELLECTUAL PROPERTY RIGHTS

The National Institute of Hydrology, Roorkee has the Intellectual Property Rights being the developer of the methodology.

WATER QUALITY MODELLING

The growing quantum of pollutant loads through point and non-point sources in streams/rivers have led to the degradation of the water quality of rivers throughout the world. Water quality in rivers may be assessed by conventional sampling and subsequent analysis, however, simulation of water quality in rivers, by using mathematical models, has been in vogue since the beginning of the last century. In addition to the municipal and industrial effluents, which may add significant amount of biochemical oxygen demand (BOD), streams are subjected to input from agricultural lands in the form of fertilizers. Such situation may lead to dissolved oxygen (DO) depletion to such an extent that aquatic life in the stream may not be able to reproduce and survive. In addition to this, different water quality pollutants in high concentrations are added to the river, which may seriously affect the health of the river.

Many rivers in India as well as abroad are receiving threats to their aquatic life. It is important and timely that a rigorous approach to the water quality modelling of such streams/rivers be undertaken. QUAL2EU (Enhanced Stream Water Quality Model with Uncertainty Analysis) is a widely used mathematical model that simulates 15 water quality constituents in branching stream systems. The studies have been undertaken by the Institute to get an insight into existing water quality model QUAL2EU. One of the most important parameter for simulation of BOD and DO in a water quality model is reaeration coefficient. In the Institute a criteriion has been evolved for estimating reaeration coefficients based on Froude number concept that provides better results and minimizes error estimates.

TECHNOLOGY

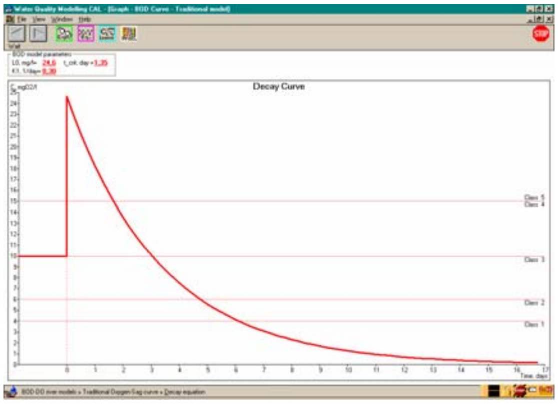
QUAL2EU model uses a finite-difference solution of the advective-dispersive mass transport and reaction equations. A stream reach is divided into a number of computational elements, and for each computational element, a hydrologic balance in terms of stream flow (e.g., m^3/s), a heat balance in terms of temperature (e.g., ^oC), and a material balance in terms of concentration (e.g., mg/l) are written. Both advective and dispersive transport processes are considered in the material balance. Mass is gained or lost from the computational element by transport processes, wastewater discharges, and withdrawals. Mass can also be gained or lost by internal processes such as release of mass from benthic sources or biological transformations. The QUAL2EU model has been extensively used in developed countries. However, its application is very limited in Indian context.

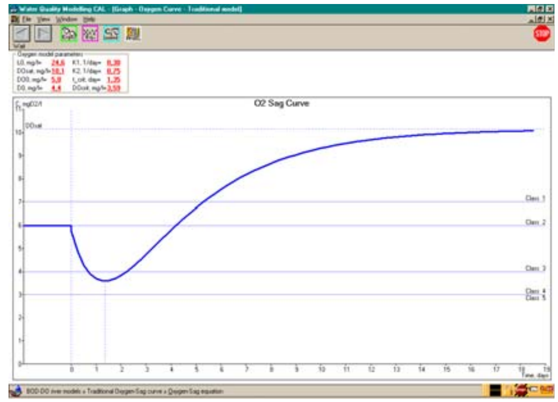
Reaeration Coefficient:

One of the major phenomena contributing to the biochemical oxidation in waters containing degradable materials is atmospheric reaeration. In the biological treatment of wastewater, aeration is an important process employed to raise the dissolved oxygen (DO) level to allow aerobic bacteria to reduce biochemical oxygen demand of the effluent resulting in improvement in the water quality. The oxygen supplied must be at a rate sufficient to at least balance the rate of removal of the active biomass. Reaeration is the process of oxygen exchange between the atmosphere and water body in contact with the atmosphere. Because the reaeration coefficient is one of the parameters necessary for water quality modelling, it is essential that techniques be available for measuring or predicting this coefficient with an acceptable degree of accuracy. The value of reaeration coefficient (K_2) can be evaluated using the dissolved oxygen balance technique and data sets of distinct terrestrial streams/channels.

The QUAL2EU programme simulates changes in flow conditions along the stream by computing a series of steady-state water surface profiles. The calculated stream-flow rate, velocity, cross-sectional area, and water depth serve as a basis for determining the heat and mass fluxes into and out of each computational element due to flow. Mass balance determines the concentrations of conservative minerals, coliform bacteria, and non-conservative constituents at each computational element. In addition to material fluxes, major processes included in mass balance are transformation of nutrients, algal production, benthic and carbonaceous demand, atmospheric reaeration, and the effect of these processes on the dissolved oxygen balance. The model also estimates the waste assimilative capacity of river, waste load allocation, minimum flow requirement, flow augmentation and uncertainty involved at various river reaches.

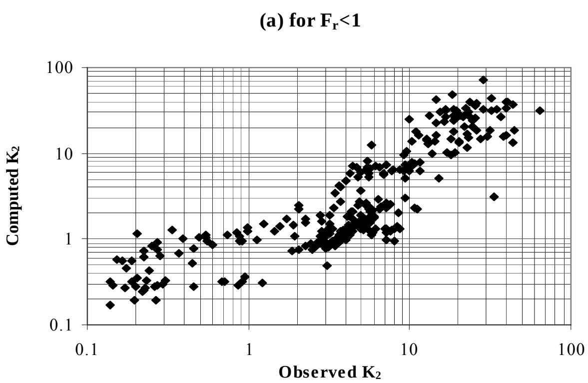
The data of River Kali (Uttar Pradesh), River Pachin (Assam), River Krishna (Andhra Pradesh), River Yamuna (Uttar Pradesh), and River Gomti (Uttar Pradesh) were used to simulate water quality at different locations of each stream using QUAL2EU.

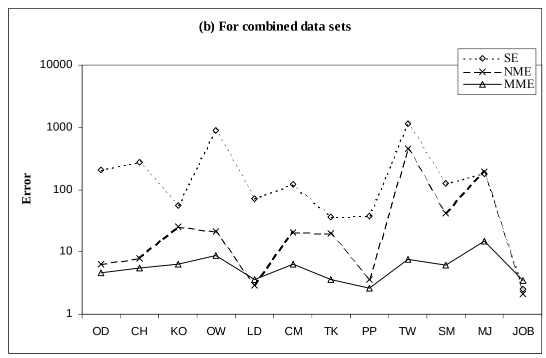




BOD Decay **Oxygen Sag**

Every stream has its own capacity to purify the organic matters disposed into the flowing water, generally known as “self purification capacity” or “waste assimilative capacity” of the





Reaeration coefficients **Error estimates**

stream. The most important consideration in determining the waste assimilative capacity of a stream is its ability to maintain an adequate dissolved oxygen concentration. Dissolved oxygen concentrations in stream are controlled mainly by atmospheric reaeration. The developed criterion for estimation of reaeration coefficient by the Institute is helpful in accurate estimation of Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) in rivers/streams for further analysis. The criteria for reaeration coefficients have been evolved using the data sets of different rivers in the world and data of the Kali, the Ganga and the Yamuna Rivers in India.

ENVIRONMENTAL IMPACT

Instead of any adverse impact, it will help in improving the environment.

ECONOMICS

As this technique provides the information on river/stream pollution status, therefore it will have tangible and intangible benefits.

BENEFICIARIES

Central Pollution Control Board, Central Water Commission, State Pollution Control Board, State Water Resources Department, etc and other non-governmental organisations.

INTELLECTUAL PROPERTY RIGHTS

The mathematical model is a public domain and any individual can procure from the market. However, the Institute has rights for the application of reaeration equations.

WEIGHING RAIN GAUGE

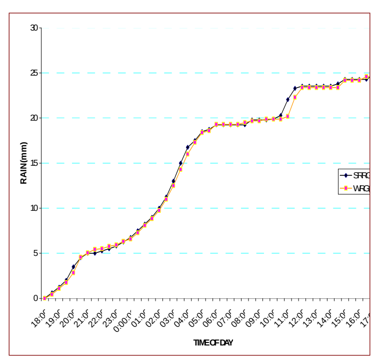
NIH has developed a Weighing Rain Gauge (WRG), which works on the principal of converting the weight of collected precipitation into equivalent depth of accumulated water. The WRG offers a great advantage over conventional systems by making possible high-resolution continuous measurement of the rainfall intensity and the total accumulated rainfall. Use of the instrument would provide reliable rainfall data, especially from the remote and difficult areas, to the hydrologists and water resource managers.

TECHNOLOGY

The instrument is based on a weighing mechanism. A strain gauge based load cell is used to weigh the accumulated rain on a platform. Rainfall is calculated from the measured weight of the accumulated water, where every increase in the weight represents a certain volume of rain. The accumulated rain after a preset level is drained out using a siphon arrangement. A collector rim of 205mm diameter is used on an outer container, from which the water is collected through a funnel into an inner container. The inner container rests on the load cell and has been designed to store 10 cm of rainfall. A data logger has been used with the load cell sensor for measuring and recording the rainfall data. The data logger continuously records the weight (and equivalent depth) of the accumulated rain in an on-board solid-state memory, which can be downloaded to a laptop computer, whenever required.

Results of the comparison with conventional SRRG and Tipping Bucket rain gauges are encouraging, normally within the error of ± 5%.

- Catch Area: 205 mm
- Capacity: 100 mm rain in one siphon-cycle
- Resolution: 0.1 mm; Accuracy: within 3%
- Operating Temp. Range: -15 to 50 deg C



ENVIRONMENTAL IMPACT

The technology has no adverse environmental impact.

ECONOMICS

Approximate cost of the sensor & accessories: Rs. 12,000/-, data logger & accessories: US$ 2500, and software: US$ 500.

BENEFICIARIES

Organizations and agencies involved in the monitoring of rainfall.

INTELLECTUAL PROPERTY RIGHTS

The Institute has intellectual property rights over indigenous component (sensor) of this technology.

WEIGHING SNOW GAUGE

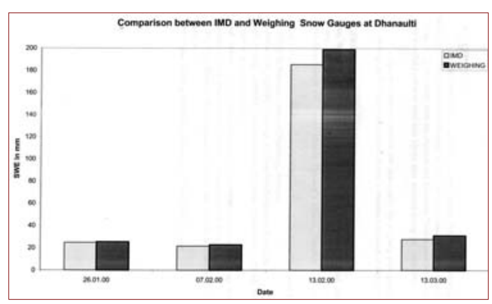
NIH has developed a Weighing Snow Gauge (WSG), which works on the principal of converting the weight of collected snow into equivalent depth of accumulated water. The WSG offers a great advantage over conventional systems by making possible high-resolution continuous measurement of snowfall, and it does not require any antifreeze solution or heater for the measurement of SWE. Use of the instrument would provide reliable snowfall data, especially from the remote and difficult areas, to the hydrologists and water resource managers.

TECHNOLOGY

The instrument is based on a weighing mechanism. A strain gauge based load cell, in combination with a data logger, is used to weigh the accumulated snow on a platform. Precipitation is calculated from the measured weight of the accumulated snow, where every increase in the weight represents a certain volume of precipitation. The snowmelt, and any rainwater, is drained out through a slit opening in the weighing platform. The data logger continuously records the weight (and SWE) of the accumulated snow in an on-board solid-state memory, which can be downloaded to a laptop computer, whenever required.

Results of the comparison with conventional IMD snow gauge are encouraging, normally within the error of ± 5-10%.

- Platform Catch Area: 500mm X 500 mm
- Capacity: 300 kg (120 cm SWE)
- Resolution: 0.1 mm; Accuracy: within 3%
- Operating Temp. Range: -15 to 50 deg C



ENVIRONMENTAL IMPACT

The technology has no adverse environmental impact.

ECONOMICS

Approximate cost of the sensor & accessories: Rs. 27,000/-, data logger & accessories: US$ 2500, and software: US$ 500.

BENEFICIARIES

The main beneficiaries of the technology would be organizations and agencies involved in the monitoring of snowfall.

INTELLECTUAL PROPEIETY RIGHTS

The technology has been developed at the National Institute of Hydrology, Roorkee, therefore, NIH has the intellectual property rights over indigenous component of this technology.