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Research and Development in Hydrology hydrologic investigations and high tech applications

By

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HYDROLOGICAL INVESTIGATIONS AND HIGH TECH. APPLICATIONS

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1.0 INTRODUCTION

Rapid increase in population and unpredictable behavior of nature have caused change in the water need which requires extensive investigations of various hydrological parameters and processes. Infiltration of rain or irrigation water through the surface soil is a very important parameter in order to assess the surface runoff and groundwater recharge. The knowledge of soil moisture availability and its movement in unsaturated zone is not only useful for the planning of conjunctive use of groundwater but also the agricultural activities can be planned in a judicious manner. Hydrological soil classification is also very useful from hydrological and agricultural point of views. In areas where availability of surface water and groundwater is limited, the loss of surface and sub-surface water due to evaporation and evapotranspiration can be reduced by controlling some hydrological and agricultural activities. The availability of surface water can be increased by reducing the loss of precipitation due to interception which mainly depends on the type of vegetal cover and land use pattern.

The advance techniques like isotope applications, remote sensing techniques, microprocessor based instrumentation and data base management techniques using software like GIS etc. are the boon to hydrology. But it has been observed that a country like India which is capable to absorb/utilize these latest advances of science and technology, is in fact not able to provide the hydrological outputs in a desired manner, due to lack of coordinated efforts and not giving the due importance to the investigations part including use of high tech. applications.

Every year, many parts of the country suffer badly due to floods, droughts and other natural disasters related with excess and scarcity of water, but, still our efforts are going on to find out the solution to these problems. Actually, the investigations part should be given due consideration while formulating and implementing a project/scheme and the use of high tech. applications should now be a practice in all our hydrological activities.

In this paper, the hydrological investigations for the few important hydrological parameters/processes have been described along with the high tech. applications like Isotope techniques, Remote Sensing Applications, advance instrumentation techniques and data base management system for investigations, hydrological data collection, storage, retrieval and analysis. The research and development activities required to be taken care in our country and thrust areas in these fields are also mentioned along with recommendations in brief.

2.0 NEED FOR R & D ACTIVITIES AND PRESENT STATUS

2.1 Hydrological Investigations

Hydrological investigations is the back bone of hydrological activities. As far as the correct information of various hydrological parameters/processes will be available, the future predictions and judicious planning to conserve out water resources will be more near to the reality. There are many hydrological and hydrometeorological parameters / processes which should be thoroughly investigated. However, in this paper those parameters have been pointed out which are of prime importance keeping in view the R & D activities required to cope up with the challenges of the present time and to fulfill the requirements of present and future.

2.1.1 Hydrological Soil Classification

Hydrological soil grouping is the classification of soils according to their hydrological response.

United states Soil Conservation Service has classified the soils into four groups based on few parameters, such as soil characteristics, minimum infiltration rate, etc.

Need for R & D Activities

Apart from characterizing soil units for their morphological and pedological characteristics, it is essential to characterize these soils for their hydrologic response to make rational estimates of components of water balance namely runoff, infiltration, groundwater recharge and soil moisture storage. Runoff estimates are also useful in soil erosion computation to suggest soil and water conservation measures on different mapping units. However, the categorization of hydrological soils only in four groups is not sufficient. We should further, investigate the relation of other hydrological and hydrochemical parameters and the categories of hydrological soil groups should be identified according to the Indian Conditions.

Present Status

In India, All India Soil and Landuse Survey (Department of Agriculture) has classified some of the soils of river valley projects. Only 75 soil series out of about 4,500 soil series have been classified. National Bureau of soil survey and land use planning (NBSS & LUP) has also classified the soils in different states like Gujarat, M.P. and West Bengal, and for other states, the work is in going on. NBSS & LUP has categorized the soils groups only taking the few parameters like soil index and permeability while NIH in a joint project with NBSS & LUP for the identification of hydrological groups of soils in different states in the country has finalised the following parameters to categorise the hydrological soil groups, i.e. soil texture, compactness, geochemical characteristics, soil moisture, infiltration rate, permeability, soil index, etc.

2.1.2 Evaporation and Evapotranspiration characteristics

Evaporation is an essential component of hydrological cycle which plays a major role in water balance studies and assessment of water availability from lakes, reservoirs, and tanks. Anticipated evaporation is a decisive element in the design of water impounding structures. Further, the knowledge of evaporation from water bodies plays a vital role in drought alleviation schemes. Evaporation from the surface of any water body is essentially determined by environmental conditions and is amenable to physical treatment based on the knowledge of factors governing it. The process of evaporation is sustained as long as there is supply of energy, moisture, a vapour pressure gradient between the water surface and the atmosphere and the speed of the wind at or near the water surface. A rough estimate indicates that about 33% of the total storage from the reservoirs, tanks and lakes, is lost through this process in our country. Evapotranspiration is the loss of water (evaporation) through stems and leaves of the trees. It depends mainly on the type of trees and landuse along with other factors which are applicable for evaporation from free surface.

Measurement of evaporation can be made either by Pan methods or by Atmometers, while estimation of evaporation can be made by Water budget method, Energy budget method, Mass transfer, Combination of energy budget & bulk aerodynamics or Evaporimeter Coefficient method. Here the energy budget method is more accurate out of all the methods for estimating evaporation from water bodies, but it requires accurate data on certain parameters like, net radiation, sunshine hours and water surface temperature. These data are not widely available in India, due to the cost involved in the procurement and maintenance of required sensors.

The methods which are currently available for estimating the evaporation from the bare soil, are applicable only for temperate climates. There is no simple methods requiring input data only to estimate evaporation and heat flux form bare soils, which are extremely important in semi arid zones.

Various methods for estimating evapotranspiration have been proposed but, there is none which is generally acceptable under all circumstances. Generally, the experimental approach using lysimeters is adopted. The empirical methods, such as Thronthwaite method, Blaney-Criddle method, Penman method and Christiansen equation are also under use.

Need for R & D activities:

It is obvious that no single method can be used, uniformly, to estimate the evaporation & ET in India due to different climatic conditions prevailing in different regions. The need for identifying a suitable method which can be employed in different climatic zones, by evaluating its applicability, is felt. For this purpose, the information on various studies conducted by different organisations have to be collected and a data bank has to be established. Studies on cost effective methods to reduce evaporation losses have to be carried out.

Present status:

In India most of the ET estimations have been made by IMD using Penman's method and the consumptive use coefficient (f) for different vegetal cover has been evaluated. The Penman method gives reliable estimates, but the problem is that extensive meteorological observations are required. Christiansen equation is widely used in India as it is simple. The Blaney-Criddle method is not popular in India as the monthly consumptive use factor, *f*, is not available for Indian conditions. For reducing evaporation losses, in India, most of the research efforts are being concentrated on devising suitable chemical retardants. Though, these research is fairly advanced in nature, specific methods suitable for different regions is not available.

2.1.3 Interception Characteristics

Interception is that portion of the precipitation which while falling on the earth's surface may be stored or collected by vegetal cover and subsequently evaporated. The volume of water so lost is called interception loss. In studies of major storm events and floods, the interception loss is generally neglected, while it may be significant in water balance studies. Precipitation falling on vegetation may be retained on leaves or blades of grass, flow down the stem of plants and becomes stem flow, or fall off the leaves to become the part of through fall. The factors influencing the interception are the ratio of the evaporating leave surface to the projectional area K, evaporation depth per hour E, and the duration of storm in hours T. In other words storm characteristics and vegetal cover characteristics. Interception varies with species composition, age, density of stems, season of the year, and with regional rainfall characteristics.

The variation in the interception loss with species and forest type is due to the difference in thickness and density of foliage and crowns. It has been reported elsewhere that in general between 0.02 and 0.1 inches of rain is held on foliage before appreciable drip takes place. Under very dense forest conditions the interception may be as high as 25% of the total precipitation.

Need for R & D activities:

So far no notable study on interceptions has been carried out in India, except a few by Forest Research Institute, Dehradun. In most water balance computations this component has been neglected while, as mentioned earlier, this is very much important. The interception characteristics should be studied under different vegetal cover in different seasons, for different climatic regions. Proper methodologies should be identified / developed to study the interception capacity of individual species under given conditions.

Present status:

The canopy penetration, stem flow and interception characteristics for various vegetal cover under Indian conditions are not readily available. Though various organisations such as agricultural universities, CSWCRTI, etc. are conducting studies in this direction, these studies are not leading to a nation wide picture.

2.1.4 Infiltration Characteristics

Infiltration of water through soil redistributes the soil water and influence plant growth and provides a buffer action in the hydrological cycle. It is strongly influenced by soil type, porosity, wetness, landuse, and amount of protection by crest formation.

Need for R & D Activities

Infiltration rate of soils is important to find out the amount of rain water entering the soil. For various water resources development and management projects, infiltration characteristics of soils is primary requirement to assess run-off potential, to plan cropping pattern, irrigation practices and management. The information relating to this characteristics of soils is not available in substantial quantity and usable format. Therefore, there is a need to have a nation wide picture on infiltration rate of soils to have proper planning of water resources projects. However, in order to reduce the man made errors during the collection of infiltration rate data in field, the advanced instrumentation should be developed. Now-a-days microprocessor based instrumenation can be developed to take care of the specific task. Therefore there is a strong need to develop automatic electronic infiltrometers using microprocessors.

Present Status

In India, for hydrological modeling of a basin, mostly index or the empirical formulae are used. Though, large number of infiltration measurements have been made in the country using different methods ranging from simple infiltrometer to rainfall simulators, yet this information is scattered and is not available to the users. Most of the infiltration studies in India are associated with irrigation schemes.

Infiltration rate data for many basins / states are not available. Preparation of maps for different basins showing the isopotal areas have not been done.

NIH has developed a microprocessor based infiltrometer which can be used to store the infiltration data automatically according to the pre programmed manner. This equipment is being checked by conducting field studies. Efforts are also being made to collect the available data on infiltration and to conduct field experiments in the areas for which infiltration rate data is not available.

2.1.5 Low Flow Measurement(using Conventional Techniques)

Stream flow is the combined result of all climatological and geographical factors that operate in a drainage basin. It is the only phase of the hydrological cycle in which the water is confined in well defined channels which permit accurate measurements to be made of the quantities involved. Other measurement of the hydrological cycle are point measurements for which the uncertainties on an ariel basis are difficult or not possible to estimate.

Good water management is based on reliable stream flow information while the final reliability of the information depends on initial field measurements. There are different uses of stream flow data, especially low flow which affects the water management such as water supply, irrigation, energy generation, industrial water use and navigation.

However, measurement errors lead to erroneous assessment of water resources which results in a bad planning and improper water resources management.

Need for R & D activities

Some of the specific errors associated with low flow measurement are listed below

i) During low flow, the depth of flow to be measured is quite shallow. This may result in erroneous measurement of the velocity of flow.

ii) In a number of rivers, there is formation of more than one channel, which may lead to incorrect measurement of flow.

iii) In many rivers, there are fair weather bridges near to the discharge measurement site. This also affect accuracy of the observed discharge.

iv) Many a times, the observers do not take proper care in the measurement of velocity while adopting wading techniques for measurement of the flow.

Seeing the importance of low flow for the planning purposes and errors in measurement a proper methodology is required. Radio tracers can be used to measure the low flow accurately. But, the use of radiotracers requires trained personnel and also, it cannot be used for routine measurements. Therefore, training courses are required to be arranged frequently and calibration of the conventional techniques with isotope techniques should be carried out to prepare the calibration curves.

Present Status

The stream flow measurement in India are carried out using the following methods;

i) Velocity Area Method
ii) Float gauging
iii) Slope Area Method
iv) Stage - discharge method
v) Weir and flumes
vi) Dilution Method

vii) Moving Boat Method
viii)Ultra sonic Method
ix) Radiotracer techniques

Out of these, i,ii and vii are most commonly used. However, Vi and ix are now also used either by few specialised departments or with their guidance by the other departments which are responsible to measure low flows like CWC etc.

2.2 HIGH TECH APPLICATIONS

Advanced technological developments and need of the time have created an environment to develop and use the high tech applications in hydrology. However, isotope techniques, remote sensing techniques, microprocessor based telemetric instrumentation and data base management systems are already in practice . But these techniques are more frequently used in developed countries in comparison to the developing countries. India has although shown keen interest in adopting these advanced techniques/systems, but due to lack of expertise and involvement of high cost ,we are not able to get the benefits out of the use of these techniques.

2.2.1 ISOTOPE APPLICATIONS

The primary function of hydrology is to provide scientific facts about water in hydrological cycle. This is being done using sophisticated scientific instrumentation and methods for managing water resources under very difficult conditions. It is always planned to get the maximum benefit of water resources with minimum harm to the environment.

The application of radioisotopes had been initiated in India in early 1960's by the Tata Institute of Fundamental Research in Gujarat and Rajasthan to determine the age of ground Water and recharge to ground water bodies. The first national symposium on the 'Application of Isotope Techniques in Hydrology and Hydraulics was organised on 26-27 November 1974 at Central Water and Power Research Station, Poona at Bhabha Atomic Research Centre (BARC), Bombay. An All India Symposium on Radioactivity and Meteorology of Radionuclides was also organised by Atomic Energy Establishment, Trombay, Bombay in 1966 in which a few research papers related to application of radioisotopes in hydrological investigations were presented. Significantly, one Ph.D. thesis with the title, 'Application of Radioisotopes to the Civil Engineering Problems' was submitted in 1968 at Poona University, Pune. The second national symposium on Isotope Application in Industry' was organised by BARC on 2-5 February 1977 in Bombay and a workshop on 'Nuclear Techniques in Hydrology' was organised by the Committee on Isotope in Industry, Department of Atomic Energy on March 19-21 1980 at National Geophysical Research Institute (NGRI), Hyderabad. It is now normal practice to include one or two sessions of 'Application of Nuclear Techniques in Hydrology' in almost all national/international seminars/symposiums organised in India.

School of Hydrology (now Department of Hydrology), University of Roorkee, Roorkee took up the teaching programme (one unit course) as elective course for master's degree in Hydrology, and experts from IAEA, Vienna, under UNDP project, prepared a standard model course for master's programme in the year 1974-75. The contents of the course covered almost the entire research component and development as reported in IAEA publication.The teaching of nuclear hydrology in some form or other, in various courses is also being done at different universities/institutions in India.

Need For R & D Activities

There seems to be no efforts made for the study of water balance and sedimentation rates in natural lakes in India using isotopes. Information is also required on the recharge zone and sources of supply of water to the lake. Isotope techniques using environmental stable and radioactive isotopes can be used with advantage for obtaining above information for carrying out water balance and taking necessary measures for maintaining environmentally sound echo system and taking steps for maintaining ecological balance of the region.

The estimation of flow in mountainous rivers is not possible with reasonable accuracy using conventional methods due to the condition of river bed and turbulent nature of river flow. Use of dilution techniques using artificial radioisotopes can be a very effective measure to estimate the stream flow with reasonable accuracy.

The construction of dams in mountainous region with basaltic foundation pose a problem of seepage and leakage through the foundation of the dam and bed of the reservoir. The use of environmental stable isotopic and artificial radioisotopes. along with the dyes can provide a very useful tool for handling such problems.

Glacier and seasonal snow covers are important source of water in high altitude region specially in northern India. The evaluation of water equivalent of snow and snow and glacier melt are important element of water resources estimation. Isotopic snow gauges have been used for estimation of point water equivalent of snow. Environmental gamma ray has also been used with advantage for this purpose abroad. Possibility of that in Indian terrain use to be explored.

Evaluation of movement of soil moisture through the unsaturated zone of the porous media, recharging groundwater and availability of soil moisture at different times in the top soil for agricultural production are very important problems these problems can be handled with more reliability using gamma ray transmission and neutron scattering probes. Gamma ray transmission technique has been found to be very suitable for these studies through laboratory and pilot studies. There is a necessity to improve this technique so that field level trials can be made and usefulness of this technique for evaluating/monitoring can be established and applied.

In Northern part of the country, there are large areas where problems of salinity being experienced specially, in areas where old waters of the saline nature are available. This situation has been experienced in Uttar Pradesh, Punjab, Haryana and in Northern Rajasthan. The dating of deeper saline water and tracing out the saline zone using suitable radioisotopes can help in taking necessary safety precautions to save the deeper aquifers from the further salinization.

The National Institute of Hydrology has recently initiated studies in the area of nuclear application to hydrology. The study programme relate to the identification of recharge zone, surface water and groundwater interaction, lake water balance and sedimentation, soil moisture movement and recharge to groundwater, stream flow measurement in mountainous rivers and leakage/seepage from dams and irrigation works.

Present Status

Environmental Isotopes(Stable)

The atoms of an element having different atomic numbers but the same atomic wight are known as its isotopes. Isotopes are of two types i.e., stable and radioactive. The stable isotopes of water molecule i.e.. ^{1}H, ^{2}H, ^{16}O, ^{17}O and ^{18}O do not decay but it is significant that various species are formed like ^{1}H ^{16}O ^{2}H ^{16}O, ^{1}H ^{18}O etc and these species are introduced by natural process in hydrological cycle. The ratio of D/H and $^{18}O/^{16}O$ are measured by using mass spectrometers and compared with sea water as standard (SMOW). There are seven mass spectrometersin the country, out of which one is at NGRI, Hyderabad, second one is at Hydrology and Tracer section Isotope Division, BARC, Bombay and third one at Physical Research Laboratory, Ahmedabad which are exclusively used for such measurements and other nuclear hydrological studies. Mass spectrometers available with Defence Laboratory, Jodhpur, Nuclear Research Laboratory, IARI, New Delhi, Atomic Minerals Division, Hyderabad and ONGC, Dehradun are also used for the measurement of stable isotopes mass ratios. These are the major facilities available in the country.

Isotope Division of BARC has used stable isotopes extensively in the study of , Salinization of groundwater in coastal Minjur aquifer near Madras, in Midnapore district of West Bengal, and salinization of groundwater in some parts of Haryana, interconnection between aquifers in Cauvery delta and surface water and groundwater interaction along river Ganga.

Physical Research Laboratory group have carried out the studies of D and ^{18}O isotopic ratios in groundwater as well as waters of rivers, lakes and hot springs etc. taken from a variety of locations in India. The groundwaters showed a large continental effect (isotopic variation of distance from coast) both in western and eastern sectors. Studies showed the most depleted ^{18}O values in the subcontinent in the high altitude lakes in Bhutan followed by Upper reaches of Ganga at Devprayag and Rishikesh, obviously due to melt waters of Himalayan glaciers.

Environmental Isotopes(Radioactive)

Tritium (^{3}H) and Carbon-14 (^{14}C) are produced by cosmic radiations and introduced by thermonuclear explosion) in the atmosphere. These are injected in the hydrological cycle by natural process. Measurement of very small quantity of these two radio active isotopes is very tedious. At present, three institutes, namely BARC, Bombay; NGRI, Hyderabad, and PRL Ahmedabad have such facilities in India.

Cs-137 and Pb-210 are also environmental radioisotopes which are used to study the sedimentation rates in lakes and reservoirs. However, studies using these isotopes are not carried out in India except a few by PRL and BARC> Now NIH has taken up a project on lake Nainital in UP, where these techniques will be used.

BARC has also carried out studies on ground water salinity and recharge in Midnapore, West Bengal using environmental tritium.

Artificial Isotopes(Radioactive)

Radioactive isotopes are produced artificially under controlled conditions in the laboratories. The artificial radio-isotopes like tritium, potassium cobalt-cyanide, ^{24}Na, ^{32}P, ^{60}Co, ^{82}Br, ^{86}Rb, ^{89}Sr, ^{90}Sr, ^{131}I, ^{134}Cs, ^{137}Cs, ^{241}Am are frequently used for various types of hydrological investigations.

Radio active isotopes have three unique properties which are particularly useful in hydrology, i.e. penetrability of radiations, radioactive decay with time and detectability in minute quantity. The artificial radioisotopes can be obtained from Bhabha-Atomic Research Centre, Trombay, Bombay while the required equipment can be procured from Electronics Corporation of India, Ltd, Cherapalli, Hyderabad.

Soil Moisture Probes:

Neutron-scattering probe for the determination of moisture content in soil strata is now commercially available. This probes is used to monitor the moisture content in situ at various depths. This equipment is available in various laboratories in India. One type of Neutron probe with Ra-Be neutron source was being manufactured in India till recent years but is now being imported. Many Neutron probes are now available with various Research and academic institutions in India.

Neutron moisture probe has been used for the study of Civil Engineering Problems and significantly a Ph.D. thesis was submitted by Jagdish Bahadur on the topic 'Radioisotope Applications in Civil Engineering Problem' in the year 1968 at Poona University, Pune. CWPRS, Pune has also used Neutron soil moisture and density probe extensively for the study of in situ surface soil density and moisture on various dam sites.

Gamma ray scattering probe is used to find the soil density at different depths.The change in soil density due to presence of water is recorded, thereby the profile of moisture is determined. Few Gamma ray scattering probes are available at various institutions in India.

These two probes, though available, are not used by various institutes extensively. One can use these probes to determine the change in moisture content in unsaturated zone (Kiran Shankar et al) and subsequently can determine the recharge values .

Neutron moisture probe has been also used at NIH Roorkee for the study of soil moisture profile and recharge to groundwater.

Gamma Ray Transmission Technique

This is the method developed by a group of scientists at University of Roorkee (Department of Physics and School of Hydrology). This techniques has been used by the scientists at UP Ground Water Department for various hydrological studies and now is being used by National Institute of Hydrology, Roorkee.

In Gamma ray transmission technique , source ^{137}Cs, ^{60}Co or ^{137}Cs and detector (NaI, Tl activated) are mounted at some distance in two tubes in such a manner that both can be lowered simultaneously without disturbing the geometry of source and detector. The attenuation of the intensity of the photon beam (gamma radiations) by soil moisture system can be used to measure the soil density. The mass absorption coefficient is same for various elements commonly found in the soil, while for hydrogen atom, it is quite large. This fact is exploited to determine the moisture content of the soil by Gamma ray transmission method. A Ph.D thesis entitled, 'Development and use of Gamma Ray Transmission Technique for the Study of Soil Moisture Profile in situ was submitted by Bhishm Kumar in the year 1982 at University of Roorkee, Roorkee.

Injected Tracer Techniques

One of the most important applications of isotopes in the field of hydrology is on the stress from the basic principle of tracing technique. There are two major requirements for a tracer i.e. (i) it must behave exactly like the traced material, (ii) it must have at least one property that distinguishes it from traced material so that it can be easily detected.

The availability of a variety of radio active isotopes with half lives extending from a few seconds to thousands of years and their easy detection in situ even in very small quantity/concentration makes them a very useful tool to be employed in hydrological investigations as tracers. The advantages of radioactive isotope in tracing experiments are as follows:

i. Emission of radiations is not affected by physical and chemical conditions of the environment.
ii. It is very easy to detect very low concentration of radioactive tracer

iii. The place of injection can be well defined and remains known very accurately.

iv. Precise quantitative interpretations are often possible from radioactive tracing experiments by following the time evaluation and space distribution of injected tracer.

The information obtained from artificial tracer experiments for a given hydrologic system is confined to a particular selected region.

There are many uses of injected tracers in hydrology, some of them are described below.

Tracer Dilution Techniques

The artificial radioisotopes like Iodine 131 , Bromine -82 and Tritium are generally used as a tracer to get the various hydrological informations like:

1. Velocity, direction and seepage loss of water from water bodies
2. Aquifer characteristics like, porosity, transmissibility, hydraulic conductivity etc.
3. Interaction of water bodies and stratification of aquifers.
4. Location of barriers in grounu water flow
5. Flow net analysis.

The basic principle of these studies is based on the change in tracer concentration with the inflow of water. By knowing the rate of change of tracer concentration, the ground water flow velocity is determined. Once the ground water velocity is determined, the permeability/hydraulic conductivity of an aquifer can be determined by knowing hydraulic gradient which can be measured in situ by knowing the piezometric head at different distances from the bore hole.

Based on the rpinciple of radiotracer dilution, the low flow of mountainous rivers can be measured with desired accuracy. Discharge measurement of mountainous stream/rivers have also been carried out in India using radioisotope tracer technique by many organizations. UP IRI has carried out several experiments for the measurement of discharge of hilly rivers like Alaknanda, Baspa (a tributary of river Sutlej, Sangla and Kolo (tributary of river Rai in H.P) , Ganga, Yamuna, Song and model of Lakhwar Vyasi Dam using tritium as tracer.

BARC has also carried out the measurements of discharge in many rivers and stream including Tapti and Beas using Bromine -82 and Tritium as radioactive tracers.

Recently National Institute of Hydrology has also carried out discharge measurement study on river Teesta in Sikkim using ^{82}Br and ^{3}H in collaboration with BARC, Bombay.

Sediment transport studies have also been carried out in India mainly by Bhabha Atomic Research Centre, Bombay. Over 40 large scale sediment transport studies using either ^{46}Sc (glass) or ^{198}Au labelled silt in all major and medium ports along the Indian coastline to examine the suitability of dumping sites for dredged silt as well as the alignment of proposed navigational channels have been carried out by H&T Section of BARC.

PRL group has used seasonal variations of Uranium concentration (^{238}U, dpm/I) and its isotopic ratio ($^{234}U/^{238}U$) as tracers to estimate effluent discharge of groundwater into the Sabarmati river. The study indicated that about 7% of annual discharge through the river upstream of Ahmedabad, was derived from effluent groundwater discharge, the maximum contribution being 25% at some points of river.

Ground water pollution and dynamics of geothermal waters have also studied by BARC using artificial and environmental isotopes including stable isotopes.

2.2.2 REMOTE SENSING APPLICATIONS

Development in remote sensing has taken place with year 1913. Since, then the technology has improved. Remote sensing data are obtained not only at aircraft height but also from space. Data, airborne or spaceborne are obtained in many windows in electromagnetic spectrum both sense radiation reflected emitted from earth with sun as source of radiation and artificial radiation source other than sun. Spaceborne remote sensing data are obtained from circular orbiting sun synchronous satellites and meteorological satellites. The circular orbiting sun- synchronous satellites of the past have been LANDSAT (American satellite) series 1,2 and 3, SEASAT. Present circular orbiting sun-synchronous satellites are LANDSAT 4 and 5, IRS-1a AND 1b, spot-1, ERS-1. Meteorological satellite of the past years have been NOAA series satellites, INSAT series satellites.

Satellite remote sensors provide nominal ground resolution from 1.1 km. to 10 m. Satellites LANDSAT with MSS, LANDSAT with TM, SPOT in multispectral mode, SPOT in panchromatic mode, IRS-1A, 1B, LISS I, IRS-1A, 1B, LISS II provided nominal ground resolution of 79m, 30m, 20m, 10m, 36.25m and 72.5m respectively.

Remote sensing is applied in hydrology to study its various aspects. These aspects are landuse/vegetal cover mapping, flood inundation mapping, soil mapping, geomorphology studies, forests damage studies, water bodies study, drought study, aquifer identification, snow cover mapping and runoff estimation. In these applications both digital and visual interpretation techniques are employed.

Landuse/cover classification is carried out using a classification scheme and using visual analysis technique. In land cover mapping simple vegetation growth is observed. Flood inundation mapping is done using visual interpretation technique and flood inundation area along with landuse/cover are mapped. soil mapping is done using physiographic technique using visual interpretation. Geomorphology of ice cap is mapped using visual interpretation. In forest damage visual interpretation is employed to observe forest fire damage. In water body studies various water quality variables are correlated, regressed, and mapped. Water quality variables are studied which have significance in watershed management. Pilot study of drought is done based on surface water. Groundwater aquifers are mapped using visual interpretation technique. Ablation area and snow line are observed using visual interpretation technique. Remote sensing digital classification output are used in hydrologic model to predict runoff. Digital technique used in hydrologic application are classification and enhancement. In classification box, parallelepiped and maximum likelihood classifier are used. In general, remote sensing is a measure of surface phenomena and hence surface feature are studied more directly. But, field check is still required in the studies. Remote Sensing also requires training and experience to visually interpret data and knowledge of digital image processing technique for their application to be useful. An interpreter should also be aware of the capability and limitations of imaging systems for their better utilisation. The discrimination between objects also depends upon their spectral signature and many objects cannot be discriminated in remote sensing images (Sabin F.F. Jr. 1987).

FLOOD PLAIN/INUNDATION MAPPING

Flood inundation and landuse/landcover map of deltaic region in Mahanadi basin is mapped in LANDSAT MSS FCC data of band 1,2 and 4 of year 1985. A total of 2120 sq. km. area is mapped between latitudes of $19^{\circ}20'$N to $20^{\circ}45'$N and longitude of $85^{\circ}30'$E and $86^{\circ}57'$E (Anil Kumar et. al 1989).

Need for R & D activities

Flood plain mapping is successfully done using remote sensing. Flood plain mapping is possible by observing vegetation affected by floods. Systematic study is needed in flood plain mapping to observed many floods in river basin.

Present status

Flood plain mapping have been done for rivers (Blyth K., 1985, Anil Kumar et. al. 1989) using remotely sensed data. Anil Kumar et.al have used LANDSAT MSS FCC for flood plain mapping. Bhyth K. (1985) indicated that flood extent can be mapped by observing vegetation affected by flood.

EROSION, SEDIMENTATION, DROUGHT AND LANDUSE/VEGETAL COVER MAPPING

Das S.N. et.al (1992) have done landuse/cover mapping based on Anderson's scheme of 1976 using LANDSAT MSS FCC. Broad tonal variation and pattern are used for level one classes. Further classes are derived based on texture and tone. The data is used in runoff estimation using SCS method. Van den Brink J.W.(1986) have used NOAA-7 AVHRR data to study ephemeral streams in lower catchment of Tana river, Kenya. The usefulness of study is due to inaccessibility of the area. Considerable vegetation growth is observed in upper reaches of large lagas (term used for ephemeral streams) in image after rain. the lower reaches of larger laga's and smaller lagas are devoid of vegetation.

Srinivas P. (1989) had extended surface water area to be an indicator of drought condition. Tanks area in chittor district, Andhra Pradesh, India are computed using 1:250,000 scale FCC to Black and white data for year 1984. The area are grouped for different tank sizes and different groups along with total surface water area is plotted along with rainfall and groups are found matching. The variables are plotted for weekly values.

Need for R & D activities

Erosion and sedimentation is important from soil conservation and reservoir operation point of view. There is R&D need in finding erosion source and quantitative estimate of reservoir sedimentation. Reservoir sedimentation study is often hindered by remote sensing response of reservoir bed and remote sensing response from limited depth.

Landuse mapping is usually done by visual interpretation technique. As the land use characteristics of catchments are of dynamic nature, regular landuse mapping of land use pattern, using suitable schemes is essential.

Soil moisture study

Need for R & D activities

Soil moisture is important for crops, irrigation water management and water balance, runoff modeling. Various remote sensing methods respond to different depths of soil moisture. There is R&D need for quantitative estimation of soil moisture using remote sensing technique.

Present status

Soil moisture reduces remote sensing signature of soil. The depth response of soil moisture is variable in remote sensing wavelengths. A thermal wave length produces larger depth response of soil moisture. In visual wave lengths the response is obtained only from spin surface of soil. In thermal sensing diurnal fluctuation of temperature is an indicator of soil moisture increase in surface soil up to depth of order of 10.5 of cm. The fluctuation reduces with increase in soil moisture (Bhyth K., 1985).

SNOW COVER MAPPING

Bindschadler R. et.al (1992) have observed ablation area and summer snow line on LANDSAT TM and SEASAT SAR data. On TM data as well as SAR data ablation area has given dark signature. The TM band 4 is used. Snow line determined using SAR and LANDSAT TM band 4 has not been same. In SAR image snow has been found to be shifted inland. Snow line is studies on color composite of TM and SAR in red and blue respectively. Both images are co-registered prior to preparation of color composite. Bindschadler h. et.al (1992) have done study of ice sheet using TM and SAR data. Ablation area is observed is dark tone in TM band 4 and SAR.

Need for R & D activities

Snow cover is very important hydrologic variable in snow melt fed river's summer season runoff. Snow cover variable is mapped using remote sensing technique. There is R&D need for finding methods in computation of snow area, depth and densities.

Present status

Snow cover produces white signature in visible and infrared as well as microwave (active) wavelengths, in contrast to dark signature of ice. The snow line are observed differently in visible infrared and microwave (active) wavelengths due to microwave (active) sensing volume response (Bindschadler R. et.al, 1992).

2.2.3 HYDROLOGIC INSTRUMENTATION

With the fast technological developments, automated instrumentation has gained the momentum. Many hydrological instruments have been developed using microprocessors. These equipment can be used to collect the data automatically and the data can also be transmitted to the central station at a desired distance. Automation of laboratory equipment is essential in order to produce the correct and fast output. The standardisation of equipment and data formats is also very important to get the same results in case the equipment of different makes are used.

Development and Automation of Laboratory and field Instrumentation

Need for R & D activities

Measurement of different hydro-meteorological and hydrological parameters is largely done manually with conventional instruments, mostly mechanical and non-recording type. To keep up with the increased demand for good quality and quantity of hydrological data, it would be necessary to go in for upgradation of the present instrumentation being used at various sites.

Extensive development in microelectronics has opened the avenue for the development of the next generation of hydrological instruments, to incorporate the following features :

a. Introduction of new sensors, which produce an electrical signal, are less sensitive to mechanical effects, e.g. silting, clogging, drag; elimination, to the extent possible, of moving components in the sensors;

b. Variability of the time of sampling with provisions for automatic compliance with the sampling instructions at the site;

c. Compact storage of the signal in digital form at the site, including facility for transfer to different devices, e.g. computer, chart-recorder, printer;

d. Primary processing of the raw signals according to different requirements, including the statistical analyses;

e. Automatic error warning;
f. Low power transmission of the signal by remote control or telemetry;

Present Status

Presently, most of the hydrological data collection is done either manually or by using semi automatic equipment. However, few organisations like CWC, few state irrigation and water resources departments and institutes like NIH have imported few equipment which are being used to collect various hydrological and hydrometeorological parameters. But, the manufacturing of completely automatic equipment using data loggers (microprocessor based equipment) is very limited. The CIFT, Cochin has developed a range of equipment using microprocessors for the collection of data automatically (commercially manufactured by EMCON, Cochin on the basis of technology transferred from CIFT), but, these equipment are yet to be popularised among the users. NIH is also working to develop the import substitute of three equipment i.e. automatic water level recorder, rain gauge and sediment sampler. But, the development of automation of laboratory and field instrumentation requires more expertise and attention.

TELEMETRY FOR NETWORKING APPLICATIONS

Need for R & D activities

The retrieval of data measured at field sites using different sensors is not an easy job, especially if data is to be collected from a number of stations and if measurement frequency is high. The spatial coverage and the volume of data involved then become so large that as the only feasible as well as reliable alternative, the data is retrieved through telemetry.

Various telemetry options include (1) direct-wired connection, (2) transmission through telephone modem, (3) radio telemetry, (4) satellite telemetry, and (5) meteor-burst telemetry. The radio telemetry is the most widely used technique for data collection from remote sites, where not very large distances are involved. As this technique requires clear line-of-sight for communication between two stations, sometimes repeater stations are needed in between the field- and base-stations. Besides, repeater stations are also required for boosting the signal when transmitting over long distances.

With this technology, the data loggers can be accessed by radio telemetry which requires no physical connection from the computer to the data logger, thereby reducing the number of regular visits to the remote site. The networking of such telemetry systems, using different combinations of the field-, base-, and repeater stations, would result in reliable and efficient data collection strategies from remote sites.

Present Status:

Telemetry system for data transmission and receiving are not manufactured in India except very few by private and public sector organisations. However, few imported systems have been installed in CWC for the collection of data related with river gauging and other hydrological / hydrometeorological parameters; and in SASE, Manali for the collection of data on snow and glaciers etc. There are few other State and Central Government organisations which have obtained imported telemetric systems under some project schemes but, the utilities of such instruments are very limited.. Although few of such equipment are being developed by GCEL in India, most of the components and parts are being imported. IMD and NIC are also using telemetric system but the equipment which are used to transmit or receive the data are imported. Therefore, we do not have any standing in this field in comparison to the deveolped countries.

STANDARDISATION OF VARIOUS INSTRUMENTS

Need for R & D activities

With advancements in technology, a large number of instruments, with various degrees of automation and variety of capabilities and features, are available worldwide. Newer technologies are being developed continuously, resulting in a multitude of possibilities for any single application.

As a variety of products are available from different manufacturers, many a times user is not able to select a proper as well as optimum configuration for his application. It is, therefore, necessary that standardisation is attempted for various technologies and the resulting instruments.

Present Status:

As it is has been indicated above that large varieties of instrumentation (manual and semi-automatic) are being developed in India by private / public sector / Government organisations. Similarly, a variety of equipment (semi-automatic/automatic) are being imported by various organisations. Therefore there should be a standardisation of equipment with respect to its requirement for the collection of one or more hydrological parameters. Nothing has been done so far in this direction in our country.

AUTOMATIC DATA ACQUISITION SYSTEM

Need for R & D activities

The need for collection of reliable hydrological and meteorological data is obvious in flood and weather forecasting, and efficient water management. With conventional manual observation systems, there is often inadequate information, especially from remote areas and where observers are not readily available.

Recent advances in electronic technology have accelerated the development of data logging devices that are both compact and capable of monitoring many sensors. In order to improve the quality, quantity and/ or timely receipt of the hydro-meteorological data, the semi-automated or automated data acquisition systems are preferred.

With the use of automated data collection systems, most of the hydro-meteorological parameters can be measured reliably and continually. Moreover, the automation of data collection systems may reduce or eliminate the human observational errors. These systems are capable of collecting and storing data for a long time period and are highly reliable in both laboratory and field environments.

Such advanced instruments are now available in world market with various manufacturers. Keeping in view the vast potential and specific requirements, technical, environmental and logistic, in our country, it is high time that the development of indigenous automated data acquisition systems should be taken up.

Present Status:

In India, most of the organisations responsible to collect the hydrological and hydrometeorological data are collecting data manually. In a few cases, semi-automatic equipment have been used. Imported automatic equipment (Data Acquisition System) are also being used (in very few cases), but, several problems related with operation and maintenance are associated with the imported DAS. Therefore, as a whole, we can say that our country comes at a very low level in the case of use of Data Acquisition Systems.

2.2.4 DATABASE MANAGEMENT SYSTEMS

a) Data Storage and Retrieval System

In India, water related data are being collected and used by a large number of organizations involved in diverse tasks. Many organizations are involved in collecting the data, while some are sophisticated users of the data. As a result of this, useful hydrological data on several aspects of hydrology is available with different organizations. Due to the complexities in water resources issues and excessive cost of procuring basic data, effective data exchange between the organizations involved in hydrological studies is very much important.

Need For R & D Activities

Hydrology is an applied natural science and therefore hydrologists have to deal with vast amount of data. Moreover, with the increase in population and industrial activities, water is gradually becoming a scarce commodity rather than a freely available natural resource. Due to this, the analysis of water resources systems is becoming more and more complicated and detailed and this demands, inter alia, more frequent observation of larger number of variables. It has been estimated that the annual volume of primary information received from a single gauging station is in the neighborhood of 150,000 characters. Other observations such as water quality might produce between 300 to 600,000 characters. The summarization of these data in a water year book is a time consuming and voluminous job. Moreover, several types of statistical information is required for the analysis of hydrological systems, i.e. flood frequency determination, design flood estimation, low flow analysis and reservoir operations. The proper storage of these data in conventional way is next to impossible because of sheer volume of labour involved

The main problem in exchanging the data between two organizations is non-availability of data in a common format. Different organizations are storing their data in their own formats. This is because standard formats for hydrological data are not available. Hence, there is a need to develop standard formats for hydrological data.

Now a days Computer based Database Management Techniques are being applied for efficient handling of Hydrological Data. It consists of creating a database, updating it frequently as and when new data are available and retrieving the data from the database when desired. After carrying out validation checks and database. This updating is done at some pre-defined frequency usually monthly or fortnightly. The data file is kept either on-line storage or off-line storage. In the on-line storage mode, the data files are available for operations at all the times. However, this mode of storage is slightly expensive. In the off-line mode the data files are stored on magnetic tapes. This mode of operation is cheaper than on-line and is mostly used to store the data.

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Present Status

India Meteorological Department (IMD) has been storing climatological data on punch cards for last four decades. The daily rainfall data were being punched in 31 cards format until 1970. These are being punched in 24 cards format since 1971 onwards. In 31 cards format, each card contains a catchment number, subdivision number, latitude and longitude of the station along with station number

IMD has assigned a unique 3 digit catchment number to different catchments in India. In the 31 cards format, the catchment number, sub-division number and station number were recorded in each card. For each year, 31 cards were required and each card contained data for a specific data of each month.

For storage of data in 24 cards format, 2 records are needed for each month. The field in each record are catchment number, latitude, longitude, station number, year, month and 16/15 rainfall values.

A different schemes is used for storage of hourly rainfall data of the self recording rain gauges. This format includes element code, index number of rain gauge, state, year, month, date, card number and hourly rainfall values. The second card also has field for amount and duration of maximum one hour precipitation during 24 hour period.

The daily rainfall data collected by state government agencies are published by respective state government. The data from IMD is also available on magnetic tapes in coded form.

In 1991, a Data Acquisition, Storage and Retrieval System has been developed by National Institute of Hydrology under an Indo-Dutch Collaborative Project WAMATRA-II. This system collects the meteorological parameters like air temperature and rainfall along with other parameters without human intervention. The collected data is automatically stored on semiconductor memory of the data logger at the field which can be retrieved either through radio communication or through a battery operated Lap-top computer. The user of the data can print and/or process the data on the personal computer. He can also plot the data to visualize the variation of data with respect to time. However, this is not a general purpose system as it operates on specific hardware developed for this purpose

Presently, the Central Water Commission (CWC), River Valley authorities and State Irrigation Departments collect and compile basic surface water data of the key-stations through out the country. On the basis of a resolution passed by CBIP in 1948, the CWC started publishing the surface water data of the important river basins in India in the form of water year books beginning from the year 1951. After some time the State government agencies also started publishing the water year books in respect of important river basins in the respective states.

With the increase in pace of developmental activities, it became essential to use the computers for storage and retrieval of surface water data. The River Data Directorate and Statistics Directorate of CWC took the responsibility for establishment of a data bank for systematic collection, processing, storage and retrieval of surface water data. For this, the data from the water year books formed the basic input of computerized hydrological data bank of statistics Directorate of CWC.

The data collected since inception of various river sites up to the year 1987 have already been computerized. The basic surface water data such as Gauge and Discharge, Sedimentation and water quality for about 250 river sites in various basins have been computerized using the computer hardware facilities consisting of Micro-32 computer system and NEC-S/1000 Super Computer System in addition to several personal computers provided by National Informatics Center (NIC). The Hydrological data bank is regularly updated with the addition of data for the latest available year. Several retrieval programs have been developed by them to generate outputs for different river sites/basins in respect of the followings, viz.,

i. Daily data on gauge and discharge
ii. Ten daily data on stage and discharge
iii. Monthly summaries along with respective averages for gauge and discharge.
iv. Daily, Ten daily and monthly outputs in terms of coarse, medium and fine particles for sedimentations.

At present, Central Ground Water Board (CGWB) and State Ground Water Departments are the main organisations involved in ground water data collection and storage.

Previously, hydrological surveys were being carried out since long in the country along with the geological surveys and investigations. The data collection of hydrogeological parameters on regional basis commenced in 1969 with establishment of hydrograph network stations all over the country.

With the growing demand of water, complexities in the hydrogeological frame work and data requirements, the data base expanded and variety of data was being collected and stored on regional and local basis. Keeping this in view, from 1984, CGWB started the work for computerized storage and retrieval of ground water data. An elaborate coding mechanism has been developed by CGWB. For this purpose codes have been assigned to each state, district and river basin in which the station lies. The information stored also includes the latitude of a well and a well number. Three character codes have been chosen for the geology of the well site and water and water quality parameters. Further, the lithology of the geological units have also been codified. The data has been stored on IBM-compatible personal computers using dBASE-III plus package, in the format. The PC is linked to NEC-S/1000 and multi user possibilities of the system is being explored.

In 1988, National Institute of Hydrology has also developed a Ground Water Data Storage and Retrieval System using dBASE-III plus for U.P. Ground Water Investigation Organization (GWIO). As GWIO maintains data district wise, the data using the developed package is also stored district wise. Thus, to specify a particular well location, the name of the well station name, block name and district name have to be specified. Since the spellings of the district, block and station name may differ sometimes and also for achieving saving in the computer storage space, codes have been assigned to district name, block name and station name.

Addition of new data to the existing data can be achieved using simple commands. A menu driven interface has also been developed for ease of operation of the system.

The Data Acquisition, Storage and Retrieval System of NIH, described in meteorological data section, also stores some ground water parameters like soil temperature and soil suctions along with other parameters.

In India, the water quality monitoring, storage and retrieval are being attempted by mainly following agencies:

i. Central Water Commission
ii. Central Board for Prevention and Control of Water Pollution
iii. State Pollution Control Boards
iv. State Irrigation Departments
v. Central and State Ground Water Boards
vi. Ganga Project Directorate

The Central Water Commission has a large network quality monitoring stations. It monitors about 270 sites in India and water samples and sediment samples are collected at 1ᶜ days frequency also. The data is then recorded on prescrib format and then is transferred to Delhi for feeding to computer system in a standard format. They have also developed the program for retrieval of fortnightly data in respect of parameters such as pH, conductivity, TDS etc.

Central Pollution Control Board has adopted a three tier grid system of monitoring water quality of Indian rivers at Global level under Global Environmental Monitoring System (GEMS), at National level under Monitoring Indian National Aquatic Resources (MINARS) and at state level under Minimum Action Plan. The monitoring under these systems was started in 1979. The complete data collected and coordinated by CBPCWP, Delhi are fed to the IBM compatible PC in a standard format and a data storage and retrieval system is being used to store and retrieve data.

The Central Ground Water Board has identified about 8000 locations, where water quality samples are collected and data is analyzed. The data is being recorded on standard formats concerning the activities of Irrigation Departments, their main interest is to locate at the water quality from irrigation utility. The data at present is stored in the State in standard sheets and use of data storage and retrieval system is not there.

In the universities, sporadic studies are taken up for a specific research project. However, after the Ganga Action Plan has been taken up, 14 universities have been identified on the banks of Ganga and each has been given the responsibility of a stretch of the Ganga and the samples are regularly collected and detail analysis for about 30 parameters is carried out. The data are being stored on a data storage and retrieval system at Delhi.

The existing system of information collection, compilation and inference not only took considerable amount of time but also did not have mechanism of correcting various pieces of information (data) due to non-standardization of collection and compilation procedures, which played an instrumental role in enormous delays. Hence a satellite based government information network NICNET has been evolved by National Informatics Center to ensure a systematic procedure for information exchange among various departments, ministries of the state and central governments. To this end, NIC has established an inter city computer network to cover the entire country. They have provided seven terminals to CWC at Delhi which are connected to NEC-S/1000 system of NIC, thus providing an access to other places covered under NICNET. Similar Ministry of Water Resources, New Delhi and Central Soil and Material Research Station, New Delhi have been connected to NEC-S/1000 for access to NICNET to speedy retrieval of data through satellite. With the expansion of NICNET to the District level where the real data are generated. The capture of the rainfall, ground water and water use data could be carried out for the respective districts for onward transmission to the concerned state computer centres for the updation of the state hydrological data bank, which on further consolidation could be transmitted for the updation of National Hydrological Data Bank.

b) GEOGRAPHICAL INFORMATION SYSTEM

In hydrology geographic Information system (GIS) and remote sensing have important place, since both deal with spatial data. A GIS inputs, outputs, handles and stores spatial and non-spatial data. Remote sensing technique produces synoptic, repetitive spatial data which can be handled to produce data in hydrologic applications.

GIS and remote sensing are being used in hydrologic applications. For various hydrologic applications different remote techniques are used and different remote sensing signatures are important. In flood plain mapping important signature is vegetation. In soil moisture studies important signature in wet surface soil and techniques are from visible to thermal infrared techniques. In snow cover studies signature of snow is important in its different morphology and techniques important are visible infrared and microwave (active). In groundwater targeting surfacial signature is used and visual infrared region in remote sensing is used.

Need for R & D activities

A geographic Information System (GIS consists of hardware and software GIS deals with both spatial and non spatial data. Example of hydrologic application of GIS is runoff estimation using SCS (USDA) method. In the application overlay operation is done of soil and landuse/cover and watershed maps in GIS. R&D need in GIS is to apply GIS to many potential areas in hydrology such as erosion sedimentation studies, soil moisture studies, snow studies, groundwater studies, flood plain studies.

Present Status:

GIS are being developed and applied to hydrologic applications. first full scale GIS is Canada Geographic Information System (CGIS). The system is developed for Canada Land Inventory (CLI). The system obtains input inform of maps in UTIN projection. For input CGIS uses drum scanner and digitizing tablet. The storage of data is done in a manner that geographically closer data are stored together. Data are retrieved for polygons. Circular or irregular shaped. CGIS computer automatically areas. Manual digitizing is most used method but automatic digitizing is possible if there are not numerous short lines in maps (Marble D.F. et.al 1983). In automatic digitizing flat bed scanners have good potential for use in GIS. A commercially available flat bed scanner is tested by Carstensen L.w.Sr. et.al, 1991. Geometry and position al accuracy are stated to be a problem for use of remotely sensed data in GIS (Marble D.F. et.al. 1983). The GIS is used in computing runoff from catchment using VSGS SCS method. Das, S.N. et.al (1992) have used digitizing tablet to digitize map data. They have also used remotely sensed data as input and computed a higher value of runoff as compared to use of conventional data.

3.0 THRUST AREAS

On the basis of the above details and discussions held during various technical meetings and conferences/Seminars, following thrust areas can be identified.

A) Hydrological Investigations

i) Hydrological Soil Classification

ii) Infiltration Studies

iii) Evaporation evapotranspiration and interception

B) Isotope applications

i) Soil moisture status

ii) Low flow measurements

iii) Water balance and sedimentation of natural lakes

iv) Surface Water and Groundwater pollution

v) Water equivalent of snow (snow depth and density)

C) Remote Sensing applications

i) Snow cover mapping

ii) Flood Plain/inundation mapping

iii) Erosion, sedimentation and drought area mapping

iv) Soil moisture and surface water potential mapping

D) Hydrological Instrumentation

i) Development and automation of laboratory and field instrumentation

ii) Telemetry for networking applications

iii) Standardisation of various instruments

iv) Automatic Data acquisition system

E) Data base management system

i) Data storage and retrieval techniques.

ii) Geographical Information system.

4.0 RECOMMENDATIONS

On the basis of the details given above and discussions held during the various technical meetings, seminar/Symposia,following suggestions are made.

1. Hydrological investigations part should be given due importance while formulating and implementing project schemes.

2. More and more emphasis should be given to adopt advanced techniques for the accurate assessment and investigation of hydrological parameters and processes where some important decisions are to be taken.

3. Development of Indigenous automated hydrological instrumentation should be given prime importance and servicing and maintenance facilities for imported and sophisticated indigenous instrumentation should be planned.

4. Emphasis should be given to have the telemetric networking for the collection of hydrological and hydrometeorology data. However, this requires first, to develop, low cost indigenous automated instrumentation and then to popularise it among the users.

5. Standardization of data formats should be carried out at national and international level

6. The data storage and retrieval system should be independent of the Computer Systems.

7. The system should include all type of hydrometeorological time series and spatial data required for hydrological studies.

8. The retrieval system should be capable of providing the data usually needed for most of the hydrological studies.

9. A Geographic Information System be developed to input, output, handle and store catchment data and to develop hydrological applications.

10. Flood plain be mapped using historical data (remotely sensed) for all river basins.

11. Soil moisture studies be taken up for their importance for crops and as a hydrological variable in water balance, runoff computations.

12. Different sensors be explored to study depth, density of snow and snow cover be mapped from historical data.

13 Landslide prone area be mapped.

14. In order to give a boost and have a coordinated effort, for planning activities in the area of application of nuclear techniques to water anu related agricultural areas by the various organisations, there is a need for establishment of national committee on Nuclear Application in the Area of Hydrology and Water Resources and Applied disciplines to be coordinated by BARC. Similar activities shoild be planned in other fields by the frontal organisations in India.

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