

Chapter III

CHAPTER III

APPLICATIONS OF MODERN TECHNIQUES

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USE OF NUCLEAR HYDROLOGY IN PROJECT PLANNING AND MONITORING

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USE OF NUCLEAR HYDROLOGY IN PROJECT PLANNING AND MONITORING

INTRODUCTION

The prime function and Hydrology is to provide scientific facts about water in hydrological cycle. This is being done using sophisticated scientific instruments and techniques for managing water resources under vary difficult conditions. It is always planned to get the maximum benefit of water resource with minimum harm to the environment.

Nuclear hydrology has emerged as an advanced branch of hydrology which provides the solution to many hydrological problems accurately. In general , the various hydrological parameters which play an important role in the hydrological cycle, can be measured by employing suitable nuclear technique.

In water resources project planning nuclear techniques should be given due consideration under investigation and measurement component for the study of hydrological parameters related to the project.

The contains monitoring of the various hydrological parameters is also possible with the use of nuclear techniques to hydrology. Following hydrological parameters/studies can be measured /carried out by employing various isotope techniques.

1. Source of recharge and estimation of direct recharge to ground water.
2. Source of ground water salinity and pollution.
3. Surface water - ground water interaction.
4. Aquifer-aquifer interaction.
5. Dating of groundwater and aridzone hydrology.
6. Water-rock interaction, origin of geothermal fluid, estimation of temperature of geothermal reservoir in geothermal exploration.
7. Sedimentation in lakes and reservoirs.
8. Snow-hydrology, to estimate fraction of snow melt and ice melt in a glacier discharge studies on ice dynamics process and past climatic variations.
9. Leakage from dams/lakes/reservoirs.
10. Evaluation of recharge to the groundwater.
11. Determination. of groundwater velocity (seepage from canals etc.) and direction of flow.
12. Stream discharge measurement in hilly region.
13. Sediment transport.
14. soil moisture and density
15. Suspended sediment concentration.
16. Well Logging.

For applications mentioned at sl. no.1-8, environmental

isotopes are used while for others radioactive isotopes and instrumental techniques (Nucleonic gauges) are used.

Before going into details of nuclear techniques to hydrology, it is better to describe in brief the basics of isotopes for the better understanding of the subject.

Isotopes are the atoms of an element having same atomic number and different atomic masses, like Hydrogen possesses three isotopes having atomic number 1 and atomic masses, 1, 2 and 3.

The number of protons in the nucleus of an atom determines the characteristics of the element. This is called its atomic number and is represented by the symbol Z . Mass number or atomic weight of an atom is the sum of the number of protons and neutron in the nucleus of an atom. It is commonly designated by the symbol A .

Thus, the atomic number in the case of protium will be 1 and its mass number will also be 1 as there is only one proton in the nucleus while in the case of deuterium, the atomic number will be 1 and atomic mass 2 as nucleus has one proton and one neutron.

Similarly, the third isotope of the hydrogen possesses two neutrons and one proton in the nucleus therefore, its mass number/atomic mass will be three (3) while atomic number will be (1). Oxygen also has three isotopes having atomic number 8 and atomic masses 16, 17 and 18 respectively (^{16}O , ^{17}O , ^{18}O) and carbon has also three isotopes ^{12}C , ^{13}C and ^{14}C .

Isotopes can be further classified as stable isotopes and unstable isotopes. The stable isotopes are those which do not change their constitution with time and considered to be happy with their number and/or arrangement of protons, electrons and neutrons, while unstable atoms (Isotopes), can be also called as radio-isotopes, are those which can be considered to be energetically 'Unhappy' with the number or arrangement of electron, proton and neutron. Therefore, they attempt to become stable atoms by either spontaneously re-arranging the particles or by emitting particles from their nucleus with an accompanying loss of energy. In doing so, they will change to another type of atoms which could be stable or non-radio active atoms. Isotopes can be classified as stable Isotope (^2H , ^{13}C , ^{18}O) and unstable isotope. The later one can be further classified to natural and artificial isotopes (^3H , ^{90}Sr , ^{137}Cs). Natural isotopes can be divided into two categories i.e. environmental (cosmic rays produced- ^3H , ^{14}C , ^{32}Si) and primordial isotopes (^{238}U , ^{232}Th , ^{40}Kr).

RADIOACTIVITY

The phenomenon of conversion of unstable atoms to the stable form is called radio-activity. The unit of activity is denoted by Ci (Curie) and one Curie (1 Ci) is equal to 3.7×10^{10}

disintegrations per second .In case of very low activity, it is also denoted by Becquerel (Bq) and one Becquerel is equal to one disintegration per second (1 dps).The specific activity is denoted by Curies per gram or the activity per unit gram is known as Specific activity.The energy of disintegration or radiation is denoted by KeV or MeV

The disintegration mainly occurs, and are of our interest,can be classified as follows,

- (1) Emission of an alpha particle (Known as helium atom doubly ionized), [2 proton + 2 neutron]
- (2) Emission of a Beta particle (Electron having some kinetic energy)
- (3) Emission of a gamma ray (Photon)

Half Life

Half life of a radio isotope is the time span required for the activity to decay to one half($\frac{1}{2}$) of its initial strength/activity.Because any radio active isotope decay exponentially, it will require a definite time to fall to any given fraction of its initial strength.The different radio-active isotopes will have different half life as the decay is characterized by the properties of the atoms. The disintegration of atom can be expressed by the equation,

$$\frac{\text{Disintegrations}}{\text{time}} = \frac{dN}{dt} = -N\lambda$$

Where N is the number of atoms and λ is the decay constant of those particular atoms and

$$\text{Half life (T)} = 0.693/\lambda$$

Environmental Isotopes

Environmental isotopes are those isotopes , both stable and radioactive which occur in the environment in varying concentrations and over which the investigator has no direct control. The environmental isotopes most commonly used in hydrology are, stable isotopes, Deuterium, Oxygen-18, Carbon-13, Sulphur-34 and radioisotopes, Tritium and Carbon-14. Of these isotopes, Deuterium, Oxygen-18 and tritium being constituent of the water molecule are conservative and hence ideal water tracers. Other isotopes such as Carbon-13, Carbon-14 etc. which occur as dissolved compounds are non-conservative i.e., their physico chemical behavior is not identical to water.Other isotopes which are less commonly used, are Silicon-32, Argon-39,Krypton-81,Krypton-85 and Chlorine-36. Generally environmental isotopes are not used as an independent tool, but to supplement the hydrological and geochemical information and to help in a better understanding of the process taking place in a given

hydrological system.

Stable Isotopes = Deuterium and Oxygen-18

Deuterium and Oxygen-18 occur in the oceans in concentrations of about 310 PPM and 1990 PPM for HDO and H₂O respectively. The varying concentrations of these isotopes in natural waters can be measured in an isotope ratio mass spectrometer and are expressed as delta values where

$$\delta = \frac{R_s - R_{std}}{R_{std}} \times 10^3$$

Where R_s = Isotopic ratio (D/H or ¹⁸O/¹⁶O) of sample
 R_{std} = Isotopic ratio of standard

Values are expressed as % permil deviation with respect to a standard. The standard universally used is SMOW - Standard Mean Ocean Water. When water changes state through condensation or vaporization, an isotopic fractionation occurs due to the difference in the vapor pressures and diffusion velocities in air of different isotopic species of water (The water vapor is in equilibrium with liquid water). The isotopic fraction is inversely dependent on temperature. Hence the stable isotopic composition of precipitation gets depleted when one goes to higher latitude (latitude effect), altitude (Altitude effect) away from the coast (continental effect). A seasonal effect is also observed i.e., precipitation in rainy season is more depleted in stable isotopes compared to winter precipitation.

In contrast to the condensation process, the evaporation does not take place under equilibrium conditions. During evaporation, lower isotopic species preferentially leave the surface, so that the remaining liquid gets more and more enriched with time. The degree of enrichment depends on the relative humidity of atmosphere, temperature etc. The D and ¹⁸O of natural water when plotted obey the following correlation,

$$\delta_D = 8 \cdot \delta^{18}O + 10$$

For waters subjected to evaporation, the slope of the above line is < 8 and generally is between 4 to 6. Hot waters from geothermal areas will show a $\delta^{18}O$ shift on $\delta_D - \delta^{18}O$ plot due to exchange with the rock.

Radioisotopic : Tritium and Carbon-14

Tritium, the radioactive isotope of hydrogen has a half life of 12.23 years and emits low energy beta radiation (~ 18 Kev). Environmental concentration of tritium in natural water is given in tritium units (TU) 1 TU = 1 atom of ³H in 10¹⁸ atoms of

H. Environmental tritium in precipitation occurs from two sources. The first results from interaction of cosmic rays in

nature in the upper atmosphere with Nitrogen atoms, i. e.,
 $^{14}\text{N} + n \longrightarrow ^3\text{H} + ^{12}\text{C}$. The second is man made and has been derived since 1952 due to the detonation of thermonuclear devices (bomb tests) which has injected periodic pulses of tritium into the atmosphere. The concentration of tritium in precipitation increased by 3 order of magnitude in 1963 above the cosmic rays source. The global distribution of tritium in precipitation was obtained through IAEA - WHO network of stations collecting monthly samples, and the data are regularly published by IAEA.

The tritium content of groundwater could be used as a guide to distinguish between old water and waters containing some component of recent or modern precipitation.

Carbon-14

Carbon-14 is a radioactive isotopes of C that has a half life of 5730 years and emits beta radiation ($E_{\text{max}} = 156$ kev). Environmental carbon-14 is expressed as percent modern carbon-14 (pmc). The carbon-14 concentration of atmosphere before thermonuclear tests was 100 pmc. After the nuclear test, the concentration in the northern hemisphere increased nearly twice in 1963 and decreased subsequently. Carbon-14 is not an isotopic tracer of water molecule and it occurs in water as various species of dissolved inorganic carbon. The non-conservative nature of carbon-14 demands full use of complete water chemistry as well as ^{13}C of the dissolved carbon for the proper interpretation of ^{14}C data. The use of ^{14}C as a dating tool is based on the following radioactive equation $N = N_0 e^{-\lambda t}$

$$t = \frac{t_{1/2}}{\ln 2} \times \ln (A_0 / A_t)$$

Where A_0 and A_t are the initial and final ^{14}C activity respectively.

In routine ^{14}C dating, initial ^{14}C concentration is known by analyzing dendro-chronologically dated tree rings. However, in hydrology, the situation is much more complicated and many models has been suggested to predict the initial ^{14}C content.

APPLICATION OF ENVIRONMENTAL ISOTOPES IN HYDROLOGY

Source of recharge to the groundwater and estimation of groundwater recharge.

Management of groundwater reserves requires information on

its distribution, rate of recharge and origin. Recharge may occur by infiltration of local precipitation, surface waters, or remote recharge from high elevations where the amount of precipitation may be high. A number of studies concerning origin of groundwater have been studied using the altitude effect whereby the precipitation falling at higher elevation are depleted in stable isotopes than precipitation at lower elevations. The rate of recharge of local precipitation to the groundwater could be studied using environmental Deuterium, Oxygen-18 in the unsaturated soil profiles taking advantage of their seasonal variation. Environmental tritium in the unsaturated zone soil water could be of value, particularly in arid areas if the presence of bomb tritium peak could be detected. More details of the technique as well as examples will be presented in the second lecture.

Groundwater Salinization

Conventionally, Ionic ratios such as $\text{Na}^+ / \text{Cl}^-$, $\text{Ca}^{+2} / \text{Mg}^{+2}$, $\text{SO}_4^{-2} / \text{Cl}^-$ etc. are used to study the source of salinity.

However, in some cases, e.g. when the solubility product of the major dissolved salts is reached, the chemistry of water may undergo further secondary changes such as precipitation, ion exchange etc. Which may make it difficult to identify precisely the salinization mechanism. It is often not possible to determine from the chemical composition whether the salt content is due to evaporation or leaching of salt e.g. in irrigated area in arid zones where the evaporation is high. The use of environmental isotopes δ_D and $\delta^{18}\text{O}$ allow distinction of leaching from evaporation. Since leaching causes no isotopic change, whereas evaporation leads to isotopic enrichment. The isotopic approach is particularly useful in coastal areas where all salinity ultimately originates from marine environment so that little chemical distinction exists between salinity originating for example, from sea spray or from direct sea water encroachment from surface lagoons or connate sea water. More details with examples will be given in next lecture.

Surface Water Groundwater Interaction

Interconnection between surface waters such as rivers, lakes or reservoirs with groundwater could be studied using environmental isotopes. This is based on the fact that the surface waters have stable isotope composition significantly different from that of groundwater.

In high topographic areas, rivers usually originate from high altitudes and hence have depleted stable isotope contents compared to the groundwaters in the plains. The groundwaters

are predominantly recharged by local low altitude precipitation. Hence as the isotopic composition of the river and groundwater are different, the groundwater contribution to the river or vice versa could be ascertained.

A surface water system like or a reservoir is an evaporating body and hence its stable isotopic content gets enriched compared to the shallow groundwater nearby. The difference in stable isotopic content of the surface water and groundwater could be used to determine the contribution of surface water to the groundwater. A few case studies will be presented to illustrate the techniques involved.

Interconnection Between Aquifers

The interconnection between two groundwater bodies separated by an impermeable layer of sediments could be studied using either D or ^{18}O provided the two water bodies are isotopically different. When used simultaneously, D and ^{18}O contents define straight lines of mixing between representation points of the two end members. The isotopic technique was used to study the interconnection between shallow and deep zone in the Cauvery delta area in Tanjavur. Details will be presented in the lecture.

Groundwater Problems in Arid Areas

In arid areas, precipitation is generally low and the problem is to know whether a given groundwater body is being actively recharged i.e., whether it is a renewable resource? This could be studied using environmental isotopes. For example, if a given groundwater body contains tritium significantly above 5 TR, then it is being recharged in the post thermonuclear era i.e., after 1952. Tritium could be used to detect recharge which occurred during the last 3 to 4 decades. If the groundwater contains no Tritium, Carbon-14 could be used to date these old water. A number of hydrological studies carried out in Sahara and other arid areas using isotope techniques have shown that the deep groundwaters in these areas is generally very old. The stable isotopic content of these waters were depleted compared to present day precipitation. Hence it was concluded that they represent paleowaters recharged in pluvial times when humid and cooler climatic conditions prevailed.

Artificial Radioisotope Applications In Hydrology

The ideal radiotracer for hydrological application is tritium as HDO . However, tritium cannot be detected in-situ in the field and it has long half life (12.26 years). Hence, it is not suitable for short term studies. A number radioisotopes in suitable forms are available for field applications, a few of which are presented in table 1. Most of them could be detected in-situ in the field using Scintillation detector.

Another advantage of radiotracer is high sensitivity of detection. They can be detected at dilution of 10^{12} . Conventional chemical tracers are usually 1000 times less sensitive to detection.

Leakage From Dams Etc.

Seepage possibilities and situation in dams either at the time of site selection or during the construction or at the time of operation could pose serious problems. Injected radiotracer methods have proved to be effective in analyzing a number of such problems leading to decisions on remedial means. A few examples will be presented to illustrate the technique.

Recharge To The Groundwater From Local Precipitation

By studying the rate of infiltration, in the unsaturated zone using a radiotracer, recharge to the groundwater could be evaluated. Tritiated water is generally used. Alternatively, a gamma emitting isotope as $K_3CO(CN)_6$ labeled with ^{60}Co can be used with the advantage of in-situ detection. The injected tritium tracer method for evaluating rainfall recharge has been used by many workers in India. A number of measurements made in Sabarmati basin in Gujarat show that average recharge to the unconfined aquifer was about 8%. Our experiment in Western Rajasthan using both 3H and $K_3^{60}CO(CN)_6$ did not show significant rainfall recharge in a 3 year period. Further experiments are in progress.

Groundwater Velocity and Direction of Flow

The method involves the use of a special tracer probe which comprises of a tracer injection and mixing device, inflatable rubber packers to isolate a portion of the bore-hole and a built-in scintillation detector assembly. The probe is lowered to the desired depth in a borehole, the packers are inflated to isolate a portion of the borehole (to define the dilution volume and avoid vertical currents). The radiotracer is injected and well mixed in the dilution volume. If C_0 is the initial concentration of tracer and C concentration after time t , then filtration velocity (Darcy velocity) is given by the equation:

$$V_f = \frac{\pi d}{4 \phi} \frac{\ln(C_0/C)}{t}$$

Where d is the diameter of borehole, t is the time interval after which tracer concentration C_0 was observed. ϕ is the deformation coefficient.

The direction of groundwater flow is determined by

introducing a directionally oriented collimated detector into a borehole after injecting a suitable radiotracer. Both the techniques have been used in many countries to solve a variety of hydrological problems.

Stream Discharge Measurement

Discharge measurement in natural streams using radioactive tracers adopt a tracer balance approach. The advantage of the tracer technique over the conventional current meter method is that in the former case, the cross sectional profile of the stream need not be know. If tracer concentration 'C₀' is injected at constant rate 'q' into a stream of flow rate 'Q' and the concentration C of tracer a point down stream beyond the mixing length is measured then

$$q C_0 = Q C \qquad Q = q (C_0 / C)$$

An important precondition to the method is the requirement of complete mixing of the tracer. Many empirical formulae are available for estimating the mixing length. A number of discharge measurements have been carried out in the country using this technique. The details about the nonconventional technique for the measurement of discharge of rivers (in hilly region) are given at the end of this lecture note under the heading - "Non-conventional technique for the measurement of discharge of streams."

NUCLEONIC INSTRUMENTAL TECHNIQUES IN HYDROLOGY

Snow Gauges

Out of the several nuclear methods, the gamma ray attenuation using Co-60 source method is the most popular for snow gauging. The water content of the snow could thus be determined. Snow gauges are either fixed installations in selected locations or portable as used by survey parties.

Suspended Sediment Concentration Gauge

The principle is that the concentration of suspended sediment is related to the attenuation of gamma rays from an $^{241}_{Am}$ or $^{137}_{Cs}$ source. The method is feasible for sediment concentration greater than 1-2 g/l. They are best suited for high turbidity measurements during floods.

Soil Moisture/Density Gauge

Soil moisture gauges are usually based on the role of hydrogen in thermalising or moderating fast neutrons. The degree of

moderation of fast neutrons from $^{241}\text{Am-Be}$ sources is directly related to the moisture content. Soil density gauges use a ^{60}Co or ^{137}Cs source either in transmission or scattering mode.

Nucleonic Well Logging

The general objective is to obtain data on aquifer characteristics and their variation such as lithology, bulk density, porosity, specific yield, moisture content and water quality.

The types of nuclear logs often used are:

- Natural gamma logging for identification of lithology and stratigraphic correlation.
- Gamma-gamma logging using isotopic gamma source for bulk density measurements and porosity evaluation
- Neutron-neutron logging for moisture content measurements in the unsaturated zone and rock porosities in the saturated zone.
- Neutron activation logging for the estimation of mineralization in groundwater.

Table 1:

No.	Isotope and chemical composition	Radiation of interest	Half-life	Energy (MeV)	Minimum Detection limit $\mu\text{Ci/m}^3$
1.	^3H as HTO	Beta		12.26Yr	0.018 0.10
2.	^{51}Cr as ^{51}Cr (EDTA)	Gamma	27.8 d	0.324(9%)	0.80
3.	^{58}Co as ^{58}Co (EDTA) or $[\text{K}_3^{58}\text{Co}(\text{CN})_6]$	Gamma	71.0 d	0.81(100%) 0.51 (B^+ Annihilation)	0.06
4.	^{60}Co as ^{60}Co (EDTA) or $[\text{K}_3(\text{CN})_6]$	Gamma		5.27Yr. 1.17(100%) 1.33(100%)	0.03
5.	^{82}Br as $\text{NH}_4^{82}\text{Br}$	Gamma	35.76Hr.	.55(69%), .82(26%) .61(43%), 1.03(31%) .69(29%), 1.3(31%) .76(86%), 1.46(16%)	0.02
6.	^{131}I as K^{131}I	Gamma	8.05d	.08(2.2%), .28(5.3%) .36(82%), 0.64(9%) .72(3%)	.08
7.	^{46}Sc as glass	Gamma	64.0d	0.89(100%) 1.12(100%)	0.03

NONCONVENTIONAL TECHNIQUES FOR THE MEASUREMENT OF DISCHARGE OF STREAMS

Most of the conventional techniques for the measurement of discharge can be used at a chosen cross-section irrespective, within reason, of the behavior of water or the characteristics of the channel far upstream. Non-conventional techniques requires that a whole reach, possibly many kilometers long, satisfies a number of criteria and for this reason some preliminary studies may be necessary to determine whether gauging by nonconventional methods is possible or not. Nonconventional techniques, basically dilution techniques, are used where conventional methods of flow measurement of rivers and streams due to higher degree of turbulence are not suitable. Dilution techniques are based on the use of various suitable water tracers and detection of tracer dilution in minute quantity at the appropriate distance of the stream/river. Mainly, three types of tracers are employed for measuring low flows using dilution techniques.

- (i) Chemical tracer
- (ii) Fluorescent dyes
- (iii) Radioactive tracer

The outstanding advantage of tracer dilution gauging is that it measures the flow in an absolute way because the discharge is calculated from measurements of volume and time only; tracer concentrations need be determined only in dimensionless relative readings. Dilution methods may provide the only effective means of estimating the flows in shallow rock-stream rivers or when rivers are in extreme condition of flood or drought. Dilution gauging has gradually developed as a method in widespread use over the past 50 years or so. A very detailed account of the methods using common salt was given by Groat (1915). He and his colleagues identified many of the pitfalls in the method as a result of very painstaking experimental work more than half a century ago. Principle of the techniques, type of water tracers, selection of tracer and measuring reach, tracer quantity and its injection techniques, sampling techniques, Preparation and field activities, Empirical formulae for the estimation of mixing length, analysis of the water samples, determination of mixing length, determination of discharge, advantages and drawbacks of various dilution techniques are discussed in this lecture.

PRINCIPLE

The basic principle of the dilution technique is to mix a suitable tracer with the flowing water at a point and to observe its dilution at some other appropriate distance after its homogeneous mixing with river/stream water. There are three

basic criteria which should be strictly followed in order to get the correct information about discharge.

- (1) The tracer should not be lost in the way and it should have the flow characteristics near to water.
- (2) There should not be any inlet or outlet for the river/stream water in between the injection and sampling point.
- (3) The sampling should be carried out after the proper mixing of tracer with flowing river /stream water (the distance at which proper mixing of a tracer with flowing water of a river/ stream (from the injection point) takes place is known as mixing length).

The first two criteria can be thought of at the time of selection of suitable tracer and site for conducting the experiment, but the third criterion is most significant which requires considerable experience in order to have rough estimate of the mixing length for selecting the sampling point. In most of the cases, the sampling point is decided either by conducting a separate experiment using some tracers which can be detected insitu and provide the information of mixing length or empirical formulae are used to have a rough idea of mixing length.

There are two basic methods of dilution gauging. The constant rate injection method and the integration or instantaneous (gulp) method. The principle of dilution gauging can be well illustrated by considering the constant - rate injection method in the first instance, but it is not intended to keep the subsequent discussion of the two methods separate as the hydrological aspects of mixing in open channels are the same and are equally important for both. The dispersion of a tracer injected into a channel, is discussed below in order to define the conditions under which the basic equations for calculating the flow may be applied.

In the constant- rate injection method a tracer solution, of concentration C_1 , is injected continuously, at a volumetric rate q , for a period such that an equilibrium concentration, C_2 is established for a finite time at a sampling station downstream. Then the mass rate at which tracer enters the test reach is $(qC_1 + QC_0)$, where Q is the discharge and C_0 is the background tracer concentration in the river water. On the assumption that satisfactory mixing of the tracer with the entire flow across the section has taken place by the time the water has reached the sampling station (discussed later), the rate at which the tracer leaves the test reach is $(Q + q)C_2$

Equating these two rates gives the discharge

$$Q = q.(C_1 - C_2) / (C_2 - C_0) \quad \dots (1)$$

An approximate form of this equation is often quoted in the literature but should not be used unless it can be shown that q compared with Q , and C_2 compared with C_1 , are so small that the desired accuracy will not be affected. The reason for some caution here is that C_2 , represents the absolute plateau level, including the background contribution C_0 , and a correction for this background must not be made in the numerator. Also, the background' referred to in the above equation is solely the concentration present in the water before the addition of tracer, and this contribution must be distinguished from the so-called background components of analytical measurements which arise within the instruments or are caused by other external influences.

As well as thorough mixing, the method requires that all of the tracer passes through the sampling station- normally the cross-section at which the measurement of flow is required. However, when the flow divides, because of islands or abstractions, into two streams, either may be sampled, but the calculated flow then refers to the cross-section just upstream of the division.

In the integration method of dilution gauging, a quantity of tracer of volume V_1 and concentration C_1 is added to the river, often by a simple, steady emptying of a flask of tracer solution, and at the sampling station the passage of the entire tracer cloud is monitored to determine the relationship between concentration and time. The discharge is calculated from the equation

$$M_1 = C_1 V_1 = Q \int_{t_1}^{t_2} (C_2 - C_0) dt = Q.A$$

$$\text{or } Q = C_1 V_1 / C (t_2 - t_1) \dots(2)$$

Where M_1 is the quantity of tracer, t_1 is a time before the leading edge of the tracer cloud arrived at the sampling point and t_2 is the time after all the tracer has passed the point. $V_1 C_1$ is the total quantity of tracer injected into the stream and C is the average concentration during time interval t_2 and t_1 . A is the area under the concentration time curve. This has been illustrated in fig -1.

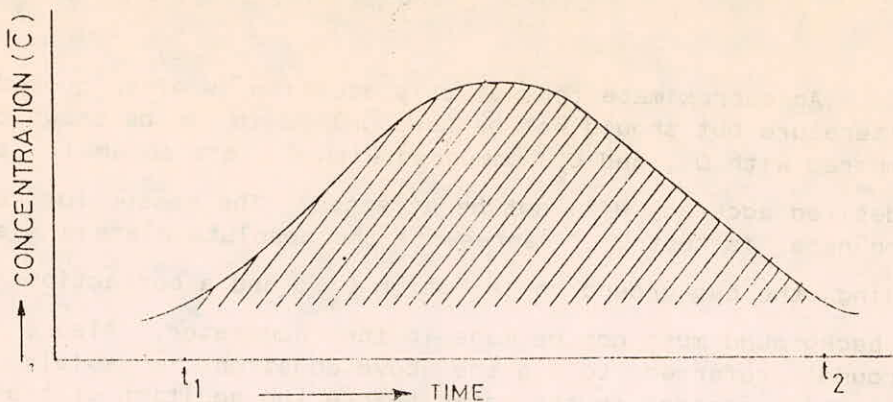


FIG. 1- CONCENTRATION CURVE

Equation -2 corresponds exactly with experimental practice and integration of the curve of $(C_2 - C_0)$ plotted against t gives the flow. However, the criterion of mixing is not that the plot of C against t is symmetrical, but that the plot of C against x is symmetrical.

Although the tracer concentration profile does not have to be integrated in the constant - rate injection method, the dispersion characteristics of the channel define the period of injection necessary to establish plateau conditions at the sampling station. A constant-rate injection may be considered as a series of gulp injections, as shown in Figure -2. The injection (1 to n) will give a series of overlapping tracer profiles which will lead to an integrated resultant tracer form by adding ordinates. Without presenting the mathematics it is clear that, in the limiting case where the elementary injections follow continuously, the minimum period of injection to obtain plateau condition will be T , because in the period T after the arrival of tracer the concentration of tracer will increase from the addition of tracer elements, but subsequently each gain from an elementary profile will be matched by a corresponding loss from an earlier profile. A similar argument will apply, at the end of the plateau, before the start of distribution 'n'. The value of T may not be known when planning the gauging exercise and it is therefore important to note from Figure 2, that to establish plateau conditions for a time period T the duration of the injection must be at least $(T + T_p)$. The duration of injection will therefore depend on D which, for some wide natural channels, will mean very long periods possibly too long to justify the additional quantity of tracer needed for the application of the constant-rate method in preference to the integration method. For a given order of accuracy this can be estimated from Figure 2, since if a quantity M_1 is suitable for the integration method, then for a plateau at a concentration corresponding to the peak of the gulp method it would be necessary to use a quantity of $M_1(1 + 2T_p/T)$ approximately.

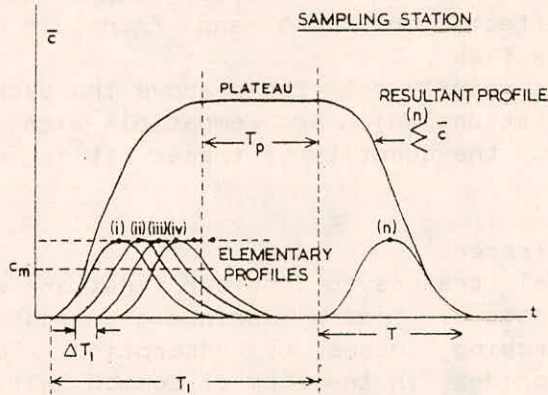
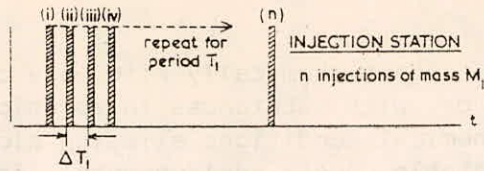


Figure 2: Constant-rate injection simulated by repeated gulp injections to show relationship between plateau duration T_p and tracer flow-through period T

Water Tracers

The various substances chosen to act as water tracers are selected for the possession of properties which provide ease of detection at low concentrations. It is possible to envisage other forms of tracer, such as heat, which may be introduced without adding any substance to the flow. Also some non-miscible tracers might be possible, such as bacterial or phase tracers (Wimpenny et al, 1972), if the component cells behave as individual tracer elements and still exist in statistically

significant concentrations at the sampling stations. The main types of tracer in use will be discussed below but the choice, in practice, may be decided by the detection apparatus available to the gauging team. For example, many modern water quality laboratories have an atomic absorption spectrophotometer, which may well be very satisfactory for determination of the tracer lithium, whereas access to a fluorimeter or nucleonic counting equipment might prove more difficult and therefore make the application of their tracers less convenient or more costly. The ideal properties of the tracer are as follows:

- (a) It should not be adsorbed on suspended solids, sediments, bed and bank materials, sample containers, or piping action or lost by evaporation

- (b) It should not react chemically with any of the surfaces given above, or with substances in solution under the pH and other chemical conditions existing along the channel.
- (c) It should be stable under environmental factors existing for the envisaged time of travel and in particular it should not show photochemical decay in sunlight.
- (d) It should not have any harmful effects on human health or adverse effects on flora and fauna in the channel particularly fish.
- (e) It should be readily detectable above the background level at concentrations which are compatible with the accuracy desired and the quantity of tracer it is convenient to inject.

(1) Chemical Tracers

The chemical tracers to consider first are simple anions, because most natural mineral surface are negatively charged thereby discouraging losses by adsorption. The traditional tracer is chloride in the form of common salt, but bromide ions may be considered equally suitable from their proven conservative properties. The use of fluoride may be limited to non-calcareous streams because of the low solubility of its calcium salt, whereas iodide has been shown to be unsatisfactory in some applications. In tests reported by Neal and Truesdale (1976) the fraction of iodide, or iodate, at a level of 0.04 mg/I, absorbed by sediments was found to range from negligible quantities to almost total uptake depending on the suspended - sediment loading and the composition of the sediment. Very high uptakes were found to occur on peat and natural peat/clay sediments in their associated fresh water. These tests confirmed indications of a similar nature obtained much earlier by Eden et al. (1952) when reservoir water containing added Iodine-131 was passed through a laboratory-scale slow sand filter. The activity of the effluent rose slowly over a period of several days to about half of that in the water before filtration. When filtration of water without tracer was resumed, Iodine - 131 was evident for many days. As sand filters trap a layer of organic debris, the implication of these results is that iodide should not be selected for work of high accuracy unless the levels of organic sediments or suspended matter can be shown experimentally to have a negligible effect on tracer recovery. The concentration of the halide ion down to about 0.02 mg/l can be determined by ion-specific electrodes under ideal conditions. Samples may have to be treated to reduce the effects of interfering ions, and considerable time and patience on the part of the operator may be required to obtain stable and repeatable readings. As ion-specific electrode systems develop they will probably replace concentration determinations based on

electrical conductivity changes, but at present the latter method with common salt as the tracer provides reliability, repeatability and simplicity, the disadvantages being that approximately 10-100 kg of salt per cubic metre per second of discharge, depending on the technique used and accuracy desired, will be required.

Salt (NaCl) has a solubility of 357-360 g/l at temperature from 0° to 40°C , respectively, and for concentrations up to about 50 mg/l, relationship between conductivity and concentration is almost linear (approximately $1.86\mu\text{ S/cm}$ per mg/l at 18°C). The minimum concentration of NaCl which may be measured with an error of ± 1 percent is given in ISO 555/1 (International Organization for Standardization, 1973) as 1 mg/l when it is $1000\mu\text{ S/cm}$ clearly, for accurate work, steady background concentration are required and these may not occur in rivers receiving sewage effluents or in winter months with intermittent run-off from salted road. Also, the background levels of chloride in rain may be very variable and may range from a few to several tens of milligrams per litre. It is important to remember that tracer materials in bulk, and common salt in particular, may be chemically impure. Salt may also contain additives to improve its physical properties or for health reasons.

The other chemical tracer which has been used, mainly in the UK, for dilution gauging in recent years is lithium, mostly as lithium chloride. Cations should, in general, be suspect with regard to cation exchange on many common minerals or bacterial slimes, but Lithium behaves in a conservative way, probably because it forms the largest of the simple hydrated alkali cations. Lithium chloride has a solubility of 637 g/l at 0°C and the element lithium can be detected in concentrations down to about 10^{-4} mg/l in the laboratory with specialized flame photometers. The range of the simple portable filter flame photometers will extend to below 1 mg/l, depending on the amount of interference from other alkali ions in the samples.

At the concentrations used for dilution gauging, Lithium does not present any hazard to man. It is used in medical practice for its tranquilizing action. However, it could possibly have adverse effects on fish. Tests with yearling rainbow trout in hard water (Department of the Environment, 1971) indicated that the 35-d median lethal concentrations was 1.4 mg/l. When dilution gauging is undertaken, tracer concentrations at such levels only exist for transient periods, but some caution in the use of lithium is necessary.

In several tracer studies conducted by the Water Research Center in UK, where Lithium has been used as part of a tracer 'cocktail' in retention studies, it has been shown that its passage may, on occasions, be slightly delayed relative to other tracers such as tritiated water, bromide or chloride, and the explanation may be the occurrence of very short-term adsorption and desorption process. An example is shown in Figure 3 (Department of the Environment, 1976) for a polluted river. In view of the discussion mixing criteria in the previous section, it is important to note that adsorption and exchange reactions will cause a skew tracer recovery curve, as illustrated in Figure 3, even if the mixing characteristics of the channel are otherwise ideal. It is clear that, as with iodide, the use of Lithium for accurate gauging work should be considered only after jar tests on sediments taken from the channel have shown that it is unlikely to be adsorbed. Measurements by the Water Research Center of the concentration of Lithium in UK rivers show that most of those into which effluents flow will have background levels ranging up to about 0.05 mg Li/l, whereas springs and unpolluted water will usually contain less than 5×10^{-4} mg Li/l.

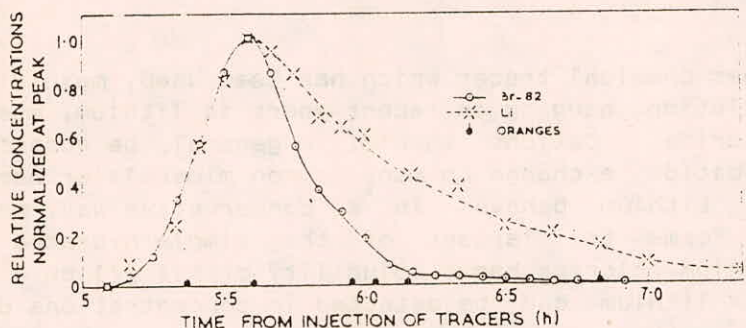


Figure 3: Example of tracer distributions 12 km downstream of the injection of a tracer cocktail (six oranges also released to assess their effectiveness as time-of-travel indicators)

Another chemical tracer that has been in widespread use, particularly in Switzerland and France, is Chromium in the form of sodium dichromate which has a solubility allowing up to about 600 g/l to be used in practice. Unpolluted natural water mostly contain negligible concentrations of chromium ions and colorimetric analysis permits detection down to about 0.2 mg/l, with further sensitivity provided by solvent extraction techniques. However, chromium is a very undesirable pollutant,

as indicated by the proposed limit for concentrations in drinking water of 0.054 mg/l. It may also have an adverse effect on some fish. Tests conducted at the Water Research Center indicate median survival times for rainbow trout ranging from 10 up to about 50 days at a concentration of 10 mg/l and about 1 day at 100 mg /l. Dichromate may not be a conservative tracer in polluted waters because its reduction to the trivalent state would cause losses by adsorption or precipitation. Other chemicals that have been used for dilution gauging include sodium nitrite and manganese sulphate, although the use of these, as of bromides and fluorides, is not thought to be widespread.

2. Fluorescent Dyes.

Fluorescent dyes have been used as mixing indicators and as tracers for gauging for almost as long as common salt. In particular the green dye fluoresceine (uranin) has been the traditional indicator. There has been more concern in recent years about pollution of rivers by organic materials and the use of dyes will be subject to greater scrutiny as time passes, particularly if fears that have been expressed about the carcinogenic properties of some of them are shown to have foundation. There are, of course, similar fears about radioisotopes, but a tracer such as Bromine-82 disappears quickly in the environment by its own decay, whereas dyes and chemicals may have a very long effective half-life in the environment.

Fluorescent dyes will not be discussed at length here because, in most cases, they are not satisfactory for dilution gauging, although Smart and Laidlaw (1977) have shown that one or two may be convenient to use for qualitative time-of-travel, retention, or dispersion studies. Their main disadvantages are photochemical decay and a tendency to adsorb (at very low concentrations) on suspended solids, or surfaces including sample containers. The two most reliable tracers are probably Rhodamine-WT and Sulpho-Rhodamine B Extra. These can be injected at concentrations of tens of grams per liter, depending on the extent to which background substances fluoresce in water. Although fluorescent dyes can be detected in samples that are colorless to the human eye, they may cause taste problems and are capable of collaring fish flesh. Modern instrumentation employing lasers makes it possible to detect dyes down to pico-gram per liter levels, but the potential advantages of such sensitivity may be outweighed by concern over the conservative properties of the tracer.

Long ago, Joly (1922) pointed out the tactical merits of radioactive tracers for dilution gauging.

3. Radioactive Tracer

I propose to utilize, in determining river discharge, the

extraordinary accuracy with which radioactive measurements can be effected. A very simple form of electroscope suffices to determine a quantity of radium to the billionth part of a gram. If, now in place of introducing salt by the hundred weight into the river, we flow into the river a few liters of a solution containing a trace of radium, and taking samples downstream examine them by the electroscope, the discharge of the river may be determined.

It took almost half a century for the use of radiotracers to be regarded as part of the normal range of techniques available to the engineer or hydrologists. No one today would consider using radium, as there are dozens of short-lived radiotracers which have since been developed and tested.

Radioactive tracers have considerable advantages when high discharges are considered. The injection solution may range in concentration up to tens of curies per litre and most isotopes are accurately detectable down to tens of pico curies per litre, so that great dilutions are possible as well as flexibility with regard to injection techniques. When chemicals are used, large systems may require such large volume of saturated solution that tactical difficulties with injection may occur and layering of the dense solutions in the channel may restrict the degree of mixing. Two radioisotopes have proved their value for accurate gauging at any rate of flow; these are Bromine-82 which may be obtained as irradiated Potassium bromide tablets and tritium in the form of tritiated water (HTO). Surface waters at the present time contain background levels of Tritium of several tens of pico curies per litre (about one order of magnitude above natural levels) caused by the contamination of the hydrosphere from nuclear bomb tests in the 1960s.

Background levels of Bromine-82 are usually zero, but there may be some variations in the counter background because of fluctuations in the cosmic and terrestrial radiation and the presence in the water of natural or bomb fallout isotopes and possible waste isotopes discharged from hospitals. Because both the decay process and the detection process are digital in nature radiotracer concentrations can be determined with exact linearity at all concentrations. Radiotracers emitting gamma-rays have the advantage of being detectable by remote means. This allows 'dirty' samples to be analysed directly without pretreatment. Additionally, factors such as pressure, temperature, and the presence of other substances cannot affect the precision with which tracer concentrations are determined. Even chemical reactions may not matter so long as the tracer stays in solution.

Bromine-82 is short lived, with a half-life of only 35.4h. It is readily detectable in situ and has been used in a wide range of hydrological studies with great success. It

disappears at a predictable rate by radioactive decay and cannot cause prolonged radioactive pollution or contamination. However Tritium, although it can be considered the ideal water tracer, since it is in the form of a water molecule, is long-lived with a half-life of 12.3 years. It must therefore be considered as a pollutant and used only for particularly important studies where short-lived isotopes cannot be used or where the time-scale of mixing justifies its use. Since it can not be detected in situ unless very specialized apparatus is available the sampling programme must be adequate to ensure that benefits of its use are secured.

The concentrations of both isotopes, at the sampling station, can be kept less than an order of magnitude below drinking water tolerance levels set for these isotopes by the International Commission on Radiological Protection (1959).

It should be noted that when Potassium bromide is irradiated to produce Bromine-82, other isotopes are formed, principally Bromine-80 m (half-life 4.6 h), Bromine-80 (half-life 18 min), and Potassium-42 (half-life 12.4 h). In order to reduce the influence of these radioisotopes to a practical minimum, the potassium bromide tablets are removed from the reactor at least three days before the time of injection. Checks of isotope purity are made by gamma-ray spectrometry and by decay measurements.

Other isotopes to consider are Sodium-24 (half-life 15 h) and Iodine-131 (half-life 8.0 d) but, as mentioned earlier, preliminary tests of both of these would have to be made to assess the possibility of adsorption losses. The use of radioisotope generators for automatic dilution gauging could be attractive for some situations. A long live parent isotope is trapped on an ion-change column and the short-lived daughter may be eluted to form the tracer injection, whenever required. Prototype equipment has been used for pipe-flow measurements by the velocity-area principle using the very short-lived daughter, Barium-137 (half life 2.6 min); of Cesium-137 which has a half-life of 30 years. For frequent short-term measurements, or mixing tests, over a period of one to two weeks, excellent in situ detection is possible using Iodine-132 (half-life 2.3 h) generated from Tellurium-132 which has a half life of 78 h.

The detection sensitivity attainable with radioisotopes can be utilized, without the administrative delays or public apprehensions associated with radiotracers, by means of post-gauging neutron-activation analysis, in which the tracer levels are derived by neutron irradiation of the water samples. The prime contender for the tracer would probably be bromide injected at much higher concentrations, in chemical terms, than when used directly in radioisotope form. High concentrations allow the

shortest possible time of sample irradiation and thus reduce the level of activation products of other elements in the sample which may interfere with the detection of the isotope required. Costs would probably confine the technique to the analysis of composite or bulk sample obtained during tracer passage and, of course, a second analysis of the injection solution (comparative dilutions may be unnecessary with this method.

To summarize, tracers are used on a 'horses for courses' basis and the winning 'horse' would be chosen by the strength of public opinion, the magnitude of the discharge, the sensitivity of instrumentation available, the cost, the remoteness of the site, and the accuracy required. When the highest accuracy is sought, and the field conditions are such that the accuracy will be limited only by the tracer characteristics, there are very few tracers, the best of which are chloride, bromide (Bromine-82), and Tritium (or stable isotopes such as Deuterium or Oxygen-18 as a tracer incorporated in the water molecule), which have proved to be reliable. In some countries, particularly India, USSR and UK, where chemical or fluorescent tracers may be in use routinely for local checks, radioactive tracers are used for calibration work where accuracy for long-term application of the results is essential.

SELECTION OF MEASURING REACH

The length of the reach required for satisfactory mixing, according to the criteria discussed in the section on principles, can be many kilometers. The criteria are based on the assumption that the dispersion coefficient does not change along the reach between the cross-sections used for the injection of tracer and for sampling. The measuring reach should therefore be of similar form and nature over the whole of its length. For example, if a tracer has become well mixed vertically and laterally at a certain point along a channel which then increases considerably in width, say on the approach to an estuary or weir, and the tracer fronts advance preferentially along a particular axis, then lateral dispersion processes would again become effective in diluting the tracer, and sampling for flow measurement would not be appropriate even though mid-stream samples might indicate a tracer profile approximating a Gaussian distribution. The helical flow induced by a bend may be advantageous in increasing the rate of lateral mixing, thus decreasing the length required for the measuring reach. Meandering reaches may be satisfactory, provided the channel and flow pattern are such that there are no dead zones.

The criteria for mixing also make it clear that there should be no ingress of water along the measuring reach because such an occurrence may be thought of as the introduction of a

negative tracer, which therefore must also be mixed completely upstream of the sampling station. However, a mixing reach can be selected independently of the position of the injection stations when it is not convenient to make the tracer injection at the head of the reach selected. For example, a reach between two tributaries may be selected as the measuring reach, whereas it may be convenient to inject the tracer into either the main stream, or the tributary, upstream of the confluence. Under these conditions, the tracer - injection geometry and period should be regarded as those existing at the confluence. Loss of water or tracer (e.g. by interaction with sediments) in the reach must be avoided or the basic tracer balance equation will no longer hold. In practice, loss of tracer by seepage through the bed may be most difficult to detect and the effect will be reflected in an erroneous high flow result with not apparent reason why its accuracy should be doubted. It is therefore necessary on occasions to select a subsidiary measuring reach, downstream of the first, where the flow and surface geology are similar. If flows determined at both stations are the same then the tracer has behaved conservatively with respect to losses by adsorption, precipitation, etc., and there has been no significant ingress of water between the station and in all probability there has been no ingress of water in the primary reach. The only way to check whether egress of water is taking place is to measure the flow by a non-tracer method. Egress of water is equivalent to diversion of some of the flow through a bifurcation and the flow measured, therefore, is representative of the discharge upstream of the zone of egress and not the volume transported past the sampling cross-section. Repeat gauging using the sampling section but long upstream reaches may help to elucidate the problem of leakage.

Empirical Formulae

A formula for predicting the length of measuring reach, from the channel characteristics, was presented by Fischer (1967). He derived an equation for estimating the dispersion coefficient D in a channel of large width-to-depth ratio and deduced the time-scale of the convective period.

$$\text{convective period} = 0.3 l^2 / R U^* \quad \dots(3)$$

Where l is the distance between the thread of maximum velocity, and the furthest distant point in the cross-section, R , is the hydraulic radius (area divided by wetted perimeter), and U^* is the shear velocity $\sqrt{(2g R_h S)}$, where S is the slope of the energy line but may be taken as the slope of the water, and g is the acceleration due to gravity. He analysed experimental data and showed that the mixing criteria for a point or line source were established after times greater than six

theoretical convective-mixing periods which, by using the mean velocity \bar{U}_x provides, a guide to the mixing distance, L; $L > 6 \times$ convective period $\times \bar{U}_x$

$$\text{i.e. } L > 1.8 l^2 \bar{U}_x / R_h U_*^* \quad \dots(4)$$

If this distance is not available, the reach selected should be at least one-half L, as given by equation (4) since Fischer found that the growth rate of the tracer-distribution curve variance became approximately linear after three convective periods.

McQuivey and Kewer (1976a) gave values of L for several rivers at various flows. In another paper (McQuivey and Keefer, 1976b) a specific test in the Mississippi using a large quantity of dye (1815 Kg Rhodamine -WT, 20 per cent solution) is described in which flow-through curves were obtained at nine locations over a distance of 288 km. The flows were 22430 m/s at the injections point and 22600 m/s at the lower end of the reach. It was estimated that vertical mixing had been accomplished in about 16 km and lateral mixing in about 80 km. Even if estimates based on equation (4) tend to be high, they are valuable in giving a maximum value of the length of reach to aim for. In practice, the maximum length available is often decided by other factors such as the length of reach available between tributaries.

There are a number of empirical formulae for estimating the mixing distance L. For a point injection in a straight reach for mixing to be within 1 per cent of complete homogeneity, is Rimmar's formula :

$$L = 0.13 b^2 C (0.7C + 2\sqrt{g})/g d \quad \dots(5)$$

Where b and d are the average width and depth of the channel, respectively and C is the Chezy coefficient of roughness which varies from about 15 to 50 for rough to smooth bed conditions. This equation is very useful because, even if little is known about the roughness of the bed, lower and upper limits can be placed on L for guidance. It is interesting to note that the value may increase or decrease as a function of river discharge and width. Day (1975) reported experimental results indicating similar findings for mountain streams of discharge up to 15 m/s and width up to 22 m. There is evidence that the mixing length of larger system increases in a more predictable (probably in the range 1-10 m³/s). If there is little chance of finding a reach even approaching the estimated length required, then a multi-point injection technique may in some cases be a solution.

To summarize, it is necessary to select a length of channel of similar geometrical form from end to end having no ingress of water, pools, or bays and inlets of large magnitude relative to

the channel dimensions. Rock sills causing waterfalls without pools upstream or downstream should not matter and in general, bends should be advantageous in decreasing the mixing distance. Reaches with bifurcations should not be chosen but island often cannot be avoided, a trivial example being those due to bridge piers. If only rudimentary data on width, depth, and type of channel are available then there is little choice other than to use Rimmar's formula. However, if it is possible to obtain information on the energy slope or water surface slope and the factor l , possibly from preliminary survey work, then equation (4) should also be used for further guidance. A valuable compilation of photograph of river channels with their roughness coefficients has been produced by Barnes (1967).

Rimmar (1960-NEL translation) presented values for the numerical constant applicable to a range of completeness of mixing and some of these values are given in Table 2. The appropriate value should be selected to replace the value 0.13 when guidance on the mixing length for more or less accurate work is required.

Table - 2 :

Completeness of mixing	Numerical coefficient to use in Rimmar's formula
10	0.074
5	0.091
1	0.130 - value usually quoted see equation (5)
0.1	0.187
0.01	0.244

Other empirical formulae are also in vogue as given below.

- D.E.Hull's formula : $L = a_1 Q^{1/3}$
- B.Andre's formula : $L = a_2 B Q^{1/3}$
- N.Yatsukura's formula : $L = 0.032 R^{1/6} B^2/a_3 n D$
- UPIRI formula : $L = K B + C$

Where, R is hydraulic radius, a is Manning's coefficient of roughness, a_1 is a constant - may be taken 50 for centre point injection, a_2 may be taken 27 for small stream with centre point injection, a_3 may be taken from 0.3 to 0.8, C and K are constants. K is 77 for bank side injection and constant C is equal to 100 as determined experimentally. The other notations have their

usual meanings.

TRACER INJECTION TECHNIQUES

When the integration method is used the injection procedure should in most cases be very straightforward, but the sampling programme must be exact. When the constant-rate injection method is used the injection procedure must be exact and may be complex, whereas the sampling programme should be straightforward. More expertise will therefore be required at the sampling station for the integration method and at the injection station for the constant rate injection method, which may also require the preparation of specialised constant-rate injection equipment at the laboratory.

It was pointed out in the section on principles that when the integration method is used, the duration of the injection is unimportant, but to lessen the chance of density effects and to reduce the maximum concentration of the tracer at the tracer release point an extended injection is preferable. There is no requirement to achieve an exact rectangular injection profile but it is more important to ensure that all of the tracer enters the flowing water and that the quantity injected can be accurately deduced from initial and final measurements. Any tracer spilled or blown away by the wind will lead to the calculated discharge being erroneously high.

It is worth while taking some precautions against loss of tracer and the best way to do this is to carry out a complete 'dummy run' possibly using a weak dye solution, in order to identify any problems and potential spill-risk points that may be present. The tracer should be released as near the water surface as possible and when the injection is made from a high bridge a plastic pipe should be used to convey the tracer down into or near the water surface. These precautions are particularly relevant when Tritium is used. Tritiated water should be released below the surface if possible to avoid any evaporation and splashing which could represent direct losses of tracer.

Various types of apparatus have been developed for the purpose of injecting tracer at constant rates. But the basic requirement is an orifice, to govern the rate of injection, connection to a constant - head supply tank. Otherwise a metering pump may be used.

For larger quantities of tracer, a reservoir tank may be used to supply a constant-level tank employing a regulating weir to maintain a steady hydrostatic head on the orifice. An orifice is less sensitive to variations in temperature than a capillary. Whatever device is used, some regular short-term periodicity in

delivery can be tolerated, since the effects will be smoothed in the channel during the preliminary mixing stage.

Small metering pumps, either of the peristaltic or reciprocating-piston type, are usually preferred for radioisotope injections because of the small total volume involved and the necessity to minimize the residual volume. It is beneficial to keep radioisotope volume small to minimize the cost and weight of lead shielding. The injection rates may be as little as a few cubic centimeters per minute and it is convenient to use a hose pipe with a flush of water to transport the isotope to the channel.

It is important to design the injection equipment in such a way that the rate of delivery of tracer into the river can be determined on site. Volume, viscosities, and therefore injection rates, will vary with temperature and when electric metering pumps are employed the stability with time of the power supply must be checked. The injection rate must be measured at the beginning and end of the period of injection and considerable skill may be required to carry out these operations accurately, particularly for radioisotopes where a compromise must be made between taking adequate samples for timing as well as volume (or mass) accuracy and keeping the sample as small as possible to reduce the radiation dose received by the operator. White et al. (1975) have described a technique whereby the sample is collected within the lead shielding, via a T-piece just downstream of the peristaltic metering pump, for a measured period of time. The sample is then transferred immediately into a previously prepared flask of water of several litres capacity which forms the first dilution stage of the serial dilutions necessary to compare the injection solution with that of the samples taken downstream. The dilution volume provides some self shielding and the problem of handling, weighing and diluting a small aliquant of 'hot' solution is avoided.

In most cases a single tracer - release outlet near mid-stream is chosen. but mid-stream should not be regarded as essential, particularly when a bridge support, which might cause local back and eddy currents, occupies this position. Injection below the centre of the arch of the bridge beneath which most of the flow occurs may then be appropriate. It may be advantageous to divide the tracer dosing line into two where the flow beneath a bridge is effectively formed into two channels. The criteria for good mixing were based on theoretical initial conditions of tracer 'injection' as a sheet across the upstream section. It must be remembered that the technique, often suggested, of making use of a multi-point injection to reduce the mixing distance applies to reduction in distance compared with a single point injection, i.e. compared with the estimate of L given by equation (5) but not compared with the requirements of basic theory

However, if it is possible to determine the relative discharge of the channel as a function of width and make a multi-point injection distribution to match, then the mixing distance may be reduced considerably in those cases where vertical mixing takes place long before complete lateral mixing, and this is usually so for wide shallow rivers. This approach simulates dividing the river longitudinally into a number of component channels and adding tracer to achieve similar tracer conditions in each channel at some point downstream. In the limit, if a matrix of tracer injection nozzles were distributed with width and depth such that the injection rate at each point matched the elementary discharge crossing each component elementary area of the cross-section, then the mixing distance would effectively be zero for the constant-rate method. (A flow gauging structure based on heating elements, using heat as the tracer, could be developed along these lines.)

An estimate of the potential benefits of multi-point injection can be demonstrated by considering the case of a wide river of uniform depth such that the discharge per unit width does not vary across the section. Consider a tracer injection from N points; the channel may then be assumed to consist of N equal channels, side by side, clearly the characteristic length l used in equation (4) will be N time smaller and so the mixing distance should be N time shorter. Therefore even a twin-injection technique might reduce the mixing distance by a factor of 4 and for similar reasons, if a bank injection of tracer is necessary, then the mixing distance should be about four times greater than that for a mid-stream injection.

Some experimental data on the degree of mixing downstream of five -point injections was given by Cole (1969) and by Sanderson in the discussion on Cole's paper. It was found that, at distances where the percentage mixing 'P' was greater than about 95, the advantage of multi-point injection was only marginal except where data on the relative discharge as a function of width were available and the injection rate was matched to this. In the latter case, the results suggest that five injection points gave an order of magnitude decrease in mixing distance compared with a single-point injection and this result would begin to approach the predicted 25 -fold reduction. The percentage mixing was defined in terms of the absolute mean deviations of concentrations C_1, C_2, \dots, C_n for samples taken across the section; at equally spaced intervals from the mean concentration C

$$P = 100 [1 - \frac{(C_a - C)^2 + (C_b - C)^2 + \dots + (C_n - C)^2}{n C^2}] \dots (6)$$

Also, in the discussion of the same paper, Ward illustrated

the difference between mixing lengths predicted by Fischer's formula (equation 4) and Rimmar's formula (equation 5) as a function of the friction factor of the stream bed.

A complex arrangement, constructed for the injection of common salt, was described in detail by Groat (1915) who used a frame of fixed dosing pipes with holes drilled at regular intervals so that injections could be made in rows at six depths simultaneously to provide a complete matrix of injection points. Various configurations and sizes of holes in the distribution pipes were investigated to obtain good distribution of tracer between the pipes, and one general design conclusion was that better distribution and mixing of tracer was obtained with fewer high -pressure jets than more numerous jets from holes subject to less hydrostatic head. To overcome the problems posed by dilution gauging within a weir structure, the Water Research Centre has used multi-point injection.

Another method used to decrease the mixing distance is artificial mixing in the stream downstream of the injection point. Submerged pumps to jet water laterally may be beneficial, or boats with outboard motors may be used to improve lateral mixing-only trial and error, both with regard to the degree of mixing obtained and the optimum position at which to use it downstream of the injection point, will show the effectiveness of such techniques. In small streams mixing by compressed air may be feasible.

QUANTITY OF RADIOACTIVE TRACER

The quantity of radioactive tracer used should be minimum for radiological safety considerations. It depends upon the extent of dispersion, the tracer goes from injection point to detection point. For safety point of view, the maximum quantity of radio-tracer which can be injected is given by the following expression

$$A_{max} = [2a\sqrt{\pi kx} / \sqrt{\bar{U}}] \text{ (MPC)} \quad \dots(7)$$

Where, A_{max} is maximum quantity of tracer to be injected
 a is cross sectional area of the stream
 k is dispersion coefficient
 x is the distance downstream from point of injection
MPC is the maximum permissible concentration in drinking water

\bar{U} is the mean linear flow velocity
Dispersion coefficient (k) may be estimated by Hull's formula

$$k = 2.5(Q \bar{U})^{1/2} \quad \dots(8)$$

However, according to Nuclear Guidebook 1 to 5 curies of

Tritium is sufficient for flow rate of 100 m³/sec.

TABLE - 3 : Radio-isotopes Generally Used as Tracers

Sl. No.	Name of radio-isotopes	Half life	Approx. Qty. of tracer reqd. for stream gauging mCi/cumec	MPC in drinking water Ci/cm ³	Countries where used
1.	Iodine, I-131	8.05 days	1.7 to 2.0	2×10^{-5}	Germany India, U.S.
2.	Bromine, Br ₋₈₂	35.50 hours	1.7 to 2.0	4×10^{-5}	Germany
3.	Sodium, Na ₋₂₄	15.00 hours	1.7 to 2.0	3×10^{-5}	France, U.S. Germany,
4.	Phosph. P ₋₃₂	14.3 days	-	2×10^{-5}	U.S.A. U.S.A.
5.	Chromium Cr ₋₅₁	27.8 days	-	2×10^{-3}	U.S.A. France
6.	Tritium, H ₋₃	12.5 Years	30.0 to 80.0	3×10^{-3}	India, U.S.
7.	Gold, Au ₋₁₉₈	64.8 hours	3.0 to 3.5	5×10^{-5}	Kenya U.S.A.

SAMPLING TECHNIQUES

The procedure for sampling will need to be as complex as that warranted by the importance of the gauging and the accuracy demanded. The essential aspect to consider for each programme of sampling is how well the samples collected at individual points in the cross-section represent the characteristics of tracer passage for every point in the section. Clearly, the more point that can be sampled, the more thorough will be the verification that the degree of mixing (defined in the previous section) is compatible with the accuracy required. A single sampling point can suffice but should, in general, be regarded as inadequate. Sampling is costly in terms of labour in the field and laboratory and a satisfactory compromise for many rivers is to select three (sometimes four) sampling points, e.g. mid-stream, left bank and right bank. To make the bank positions reasonably critical, in order to assess lateral mixing, suitable positions (to avoid debris, weeds and unrepresentative shallows) might be about 10 per cent of the width out from the bank. A fourth sampling point should be selected when part of the channel is of sufficient depth to justify checking the degree of vertical mixing. For example, relatively cold groundwater leaking into the channel could be detected by an analysis of the tracer

contents of samples collected near the bed. On deep rivers suitable sampling points might be about 1 m above the bed, to avoid sediments, and 1 m below the surface. Such positions are also suitable for positioning in situ radioisotope detectors for efficient and stable detection geometry. Otherwise the depths at which samples are taken may be chosen as shown in Figure 4.

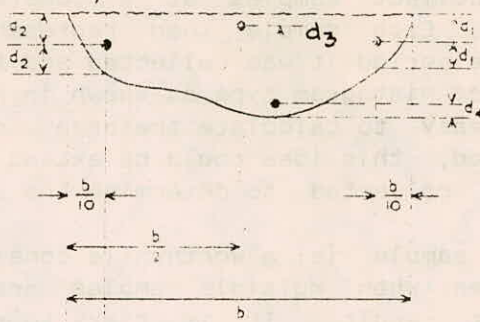


Figure 4: Sampling section defining minimum number of sampling positions for dilution gauging in natural channels (d_3 and d_4 are one-tenth max. depth or 1 m on very deep rivers)

The sampling effort needed to apply the constant-rate method might only be small, compared with the effort for the gulp method, when in situ detection is possible. It is then simply a case of observing the detector read-out and taking a series of samples at each sampling position when equilibrium conditions are indicated—possibly five samples at intervals of about 5 min for a plateau lasting one half-hour. The tracer recording may be examined to assess the mixing criteria. However, if in situ detection is not possible, then, for accurate gauging, just as many samples may be necessary as for the gulp method in order to verify that a plateau has been reached and that the curve of tracer concentration from background to plateau to background is symmetrical.

When the tracer curves for either method are determined by taking multiple samples it is important that each sample is taken from the same depth and position across the section, otherwise different distributions are being sampled. A fixed sampling tube and abstraction pump may be used for this purpose but it is essential that each sample is collected in a very short time compared with the rate at which the concentration of tracer is changing. When automatic samplers are used, the samples will be taken at equal intervals of time, but equal spacing in time is not essential; all that is required is a series of samples, with actual water abstraction time accurately recorded, in order to define the concentration-time curve. In most cases it will be necessary to have at least 20 samples of measurable concentration to define the tracer curve adequately. Automatic samplers should be checked for systematic errors due to dead water

trapped at the tube ends, cross-contamination possibilities and timing errors.

Multiple samples lead to a point-by-point definition of the tracer curve, as illustrated in Figure 5(a). The tracer concentrations between sample points must be interpolated by a best-fit procedure. A more complex technique, to overcome this difficulty, is to collect samples at a constant rate for consecutive periods. Each sample then represent the average concentration for the period it was collected and this procedure will lead to a plot of histogram type as shown in Figure 5 (b), where it is very easy to calculate the area under the curve. Clearly, as indicated, this idea could be extended so that only one bulk sample is collected to determine the area under the curve, $c dt$.

A single bulk sample is a worthwhile consideration as a back-up measure, even when multiple samples are taken, as it gives an independent result. It is risky to rely on such a technique alone because no knowledge of the tracer flow-through profile is obtained, but it is very economical and may be valuable for a person who is gauging on his own. The problem is to decide when to start and end the period of sampling when no insitu detection is possible. When the quantity of tracer used has been adequate (or more than adequate) it does not matter if the sample is started a long time before the arrival of tracer and ended some time after the whole of the tracer has passed, so long as the background concentration and discharge are steady with time.

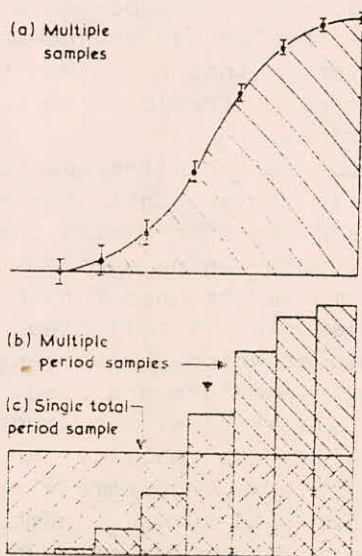


Figure 5 : Resultant tracer curve areas to integrate for three sampling techniques

A number of more complex sampling techniques to apply at a single sampling point has been suggested, both in the standards and in the literature, such as starting or ending a series of total bulk samples at different times to establish the flow by successive approximations if all the tracer had not passed by the time sampling ended. It is somewhat illogical to increase effort for such complex sampling schemes because the additional effort might be far more profitably employed by sampling at a second cross-section in order to provide a check on the behaviour of the tracer.

Alternatively, effort can always be profitably devoted to sampling more points in the sampling cross-section in order to verify mixing. In cases where it is not possible to obtain samples across the section, then several sets of samples should be taken, at points as far apart as possible relative to the mixing distance, along the bank. If some discharge is determined at the chosen points it may be assumed that the degree of mixing was satisfactory at the first station and that the probability that the tracer is confined along one bank is low because otherwise lateral dispersion would cause a systematic variation in the results with distance downstream.

In small, narrow and very turbulent streams, where there is no doubt about mixing efficiency and where conditions are almost ideal for mixing within a short reach, then single injection and sampling point may be perfectly adequate and a straight forward simplified step-by step procedure for the gauging operation can be used for routine operation, described by White et al(1975).

COSTS

Dilution gauging is a labour-intensive activity and the costs of tracer and equipment will, in most cases, be a relatively minor part of the total cost involved for the stage outlined in previous Section. During the early planning stages the objectives should be fully discussed, particularly the accuracy to aimed for. The effect of accuracy on operations, and therefore cost, should be fairly constant for accuracies poorer than about 5 percent but may markedly increase below this depending on how complex the channel is. A gauging team cannot, of course, assess the accuracy actually achieved until the end of operations, but if there is a specific target, then additional field work must be carried out to investigate potential tracer loss and the degree of mixing must be investigated., by extra sampling, in sufficient detail to match the limits of accuracy decided on. At the highest accuracies, additional effort becomes necessary to check the linearity, precision and calibration of items, such as balances, used during

the gauging work.

Costs of the entire process involved in dilution gauging have not been discussed in the literature because of the complex issues involved. For very small channels and flows, the field work may represent a considerable fraction of the total cost, whereas for large systems the preparatory and analytical stages may dominate the costs.

When conditions for gauging are very good, a gauging team may achieve an accuracy of better than 5 percent using routine procedures. On the other hand, the accuracy might be only 20 percent, but this could prove most useful and need not reflect in any way on the competence of the gauging team. On occasions, for example, when flood or drought conditions occur or when the discharge is unsteady, a result which enables the flow to be quantified even to an accuracy of 20-40 percent can be valuable.

The cost of dilution gauging will clearly be a function of discharge, since time-of-travel and tracer passage times will be greater and almost every stage of the procedures outlined will take longer as the discharge increases. Figure 6 indicates in a general way the variation of tracer costs with discharge. Actual examples of costs will not be given as they become outdated so rapidly. It is not possible to give an accurate idea of where the cross-over between radioactive and other tracer costs may be, but the cost and convenience in handling chemicals may become very much less attractive in the range 50-500 m/s. For guidance on the order of magnitude for short times-of-travel, about 100 mCi of radiotracer, 10g Rhodamine-WT, 20 percent solution, 100g Lithium and kilogram quantities of common salt per cubic metre per second of flow will be required.

The item of capital equipment which may be considered essential, for highly accurate gauging, are two top-loading balances (say Rs.15000/-), tracer detection equipment (say Rs.10,000), equipment with portable power supplies for injection and sampling (say Rs.2000/-). Most of these items will be useful for other purposes as well as dilution gauging. It must be emphasized that the items listed above as a guideline apply to cases where the accuracy will not be limited by the equipment. It is possible to conduct gauging with the most elementary equipment at small discharges. A range of ancillary apparatus is also necessary, including sample containers in quantity, timing devices, ropes, tubing, chaining, extension leads, life-jackets, and other safety equipment, protective clothing, etc. A boat with trailer, engine, etc., may be required. Also, in order to prevent any chance of cross-contamination, separate vehicles should be used to transport solutions, samples and equipment used at the injection and sampling stations.

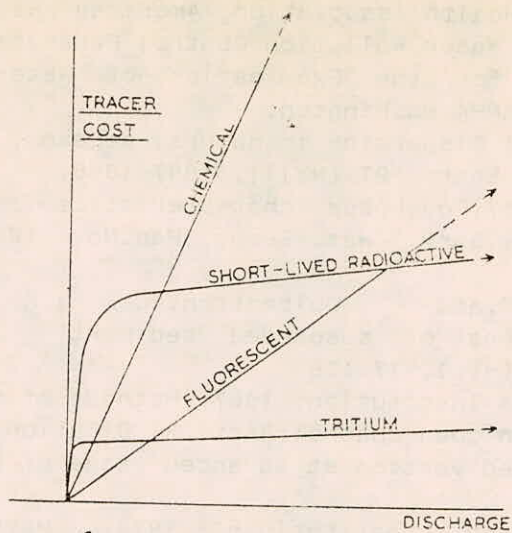


Figure 6: The cost of various types of tracer as a function of discharge

The maintenance costs attributable to dilution gauging are mostly small because much of the equipment is used for other purposes. When in situ detection equipment is used, there can be considerable maintenance costs associated with problems, of underwater connectors and general insulation breakdown problems, particularly in freezing or weather conditions. The major aim must be to keep equipment dry and clean in covers to prevent sand or dust, and airborne salt particles in coastal areas, getting into the apparatus.

CONCLUDING REMARKS

It has been shown that there are many combinations of techniques that may be used for dilution gauging. There are two basic injection techniques, several sampling techniques and a large number of possible tracers of three main types-chemical, fluorescent, and radioactive. Gauging teams tend to have their own preferred methods which they know suit their range of conditions best, and it is not possible to recommend any particular combination of techniques. However, on balance, more information is gathered using the constant-rate injection method and, where this method is possible, the chance of serious loss of accuracy should be less than when the integration method is used.

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REMOTE SENSING APPLICATIONS IN PROJECT HYDROLOGY

INTRODUCTION

Remote Sensing is a modern era technology. Not many years have passed when use of remote sensing in observing earth's resources has started the technology has developed during period of world war I and got impetus in world war II and then continually developed thereafter. Initially the technology has expanded to infrared region photography from only aerial photography. The further development has been the use of radar for detecting aircrafts. The techniques have further modified to use fixed antenna and use of optical interference phenomena. The technique has come to be known as SLAR SAR. The use of techniques have expanded to many applications concerning earth resources.

Remote sensing is a technique where information is obtained at a distance from object being sensed by collecting EMR. EMR are waves travelling at speed of 3×10^8 m/sec. For sensing of earth resources the wave's wide spectrum is selectively adopted as suitable regions for remote sensing. The regions are called remote sensing windows for sensing earth resources. The window regions correspond to regions of EMR where relative atmospheric transparency exist. The other regions are suitable for atmospheric sensing and not suited to earth resources sensing. The atmospheric non-transparency is caused due to attenuation phenomena, i.e., of scattering and absorption. The phenomena of scattering is dependent on particle size in atmosphere. The absorption is dependent of particles and molecules of gases. Barring affect of attenuation the information is travelled with EMR to remote sensing equipments at a height.

The height of placement of remote sensing equipments is varied. Accordingly the equipment platform are airbourne and space borne. The air borne platform are ordinarily aircrafts. The space borne platform are satellites, space shuttle. The information is collected onboard a platform and transmitted to the ground. All the information obtained at ground are processed and distributed to various user groups at a cost by acquiring agency.

Users involved in earth resources mapping possess familiarity with mapping techniques. The mapping techniques involves use of classification schemes and mapping projections. For classification different level are there. The classification levels are level I,

level II and level III. Level I classification are broad classification like agriculture area, forested area, urban area. Level II classification does division in level I classification. Level III classification provides sub-sub division. The need of mapping projection arises due to oblate spherical surface of earth. A oblate sphere surface is developed by techniques of cylindrical and conical projections. The cylindrical and conical projections employ cylinder or cone to envelope the earth surface touching earth surface over one or two lines. The points at earth surface are projected to enveloping object thus producing map over enveloping object which then is developed resulting in map.

REMOTE SENSING APPLICATIONS IN PROJECT HYDROLOGY

Remote sensing is a modern era technology. The benefit of remote sensing is that data are available repetitively at good scale and with synoptic view. These characteristics of remote sensing data make remote sensing data very useful in project hydrology where earth resources data are required. Many applications are possible and are operational in project hydrology using remote sensing technique. Some of the applications are discussed hereunder.

Soil erosion study

On concurrence of certain factor water causes soil erosion. The factor causing soil erosion are soil type, slope, vegetation-absence. The factor are mapping using remote sensing data. Soil cover, soil type are mapped using visual photographic interpretation technique and digital analysis of digital remote sensing data. Photo interpretation technique is a well developed technique. In photo interpretation elements of photographic interpretation are employed to identify objects in remote sensing data. The element of interpretation are tone, texture, size, shape, pattern and association. All elements help in photographic interpretation. Photographic interpretation is applied to negative, positive photographic transparencies, photographic prints, color composit-natural and false color prints at scale ranging from 1:50000 to 1:1M or smaller scale. The standard image scale for satellite remote sensing data products are 1:50,000, 1:125,000, 1:1M. Smaller scale data are available. For geostationary satellite data where resolution is very course of the order of 1 to 1000 Km., the geostationary satellite such as INSAT-series, now deployed INSAT-IC and-ID. Soil type is an important factor in soil erosion study. Soil type is

discriminated in remote sensing data based on soil forming factors vegetation, parent material, climate, slope and time. The factor results in typical soil development. The approach require delimiting land forms and associating land form to the soil type. For soil erosion computation determining quantitative value of soil erosion universal soil can equation is used. Soil erosion is important in project hydrology due to it causing agricultural land degradation and reservoir sedimentation.

Landuse and Land Cover Study

Landuse and land cover delineation is important in project hydrology. Since landuse and land cover input in many project such as command are development, water resources management. Land use and Land cover are most obvious details to be delineated by remote sensing. Green vegetation has characteristics of very high reflectance in near infrared region of reflected EMR region of remote sensing. The signature makes it possible to delineate green vegetation from other features in this wave length region of EMR. Colour composit image shows human settlements in gray tone as compared to surrounding regions. The cropped area are demarcated in remote sensing images due to their shape land high reflectance in near infrared region and red tone in false color composit of red EMR and two near infrared EMR. The moisture stress in vegetation is causes reduced leaf area index and hence less reflections in near infrared EMR as compared to healthy green vegetation. Density of vegetation cover results in varying texture in remote sensing image. Dense vegetation shows smooth texture. On the other hand sparse vegetation shows rough texture. The biomass production is also determined from remote sensing. The biomass production determination is based on fact that the amount of reflected energy varies due to plant moisture stress. The biomass production is correlated to normalised difference vegetation index (NDVI).NDVI is computed as follows.

$$NDVI = \frac{\text{Near infrared reflectance} - \text{Red or Visible reflectance}}{\text{Near infrared reflectance} + \text{Red or visible reflectance}}$$

Rainfall Determination

Rainfall measurement is done by raingauges. Remote sensing technique allows rainfall measurement using radar. Radar is placed at a raingauge radar station. The radar sends beam of microwave energy. The microwave energy back scattered-signal-strength- is measured. The returning signal strength is related with rainfall amount Rainfall occurs in form of water

droplets. Due to large diameter of water droplets, the droplets causes scattering phenomena in radar wave increasing the amount of energy scattered back to emitting station. The strength of returning signal is measured. Larger the diameter of water droplets, larger the no. of water droplets more the amount of rainfall and more the amount of energy returned. The two quantities are directly proportional. The calibration is done to obtain measurements of rainfall from remote sensing measurements.

The satellite measurements of rainfall is done through infrared region measurements of the clouds. Due to high absorption of light wave in infrared region by water vapours, the images gives darker tones in infrared sensing defracting rain causing clouds.

Surface Water Monitoring

Surface Water monitoring is important in surface water project hydrology. Remote sensing has capability in accurately demarcating the spatial expanse of surface water, aquatic vegetation depiction over images, demarcation of sediment and thermal plumes in surface water bodies and water bathymetry.

Spatial expanse of surface water is demarcated in remote sensing data due to high land water contrast observed. Land is possessing high reflectance property due to its high absorption of light waves. In thermal infrared due to thermal inertia a higher land water contrast is observed. Day time thermal infrared images show brighter land tone and darker water tone. The reversal of tone occurs in night time thermal images. Volume determination is based on area volume curve as used in case of volume determination through area-elevation volume curve method.

Aquatic vegetation shows typical vegetation signature in remote sensing images green vegetation has signature of high value in infrared region and low value in visible region except green region of EMR. The properly discriminates aquatic vegetation in surface water. The aquatic vegetation causes reduction in surface water body capacity due to deposition of dead vegetation at the bottom and raising of bottom. The phenomena is called lake purification.

The sediment gives high reflection from surface water due to scattering caused by sediment in suspension. The movement of sediment plume is detected in surface water features due to this phenomena. The thermal plume are demarcated in thermal remote sensing images. The thermal plume depicts higher signature at thermal plume source and gradually reducing towards for end of the plume as hot water mixes with cold water.

The surface water bathymetry is provided in ultraviolet and blue region remote sensing. In these low wavelengths EMR the absorption by water is low and hence the clear water penetration is high. Thus, for clear water the shallow water region surface water bathymetry is very effective. The penetration of light wave in ultraviolet region is of order of a meter.

River Basin Runoff Modelling

Runoff is volume of water flowing in stream in unit time. Runoff results due to precipitation in river basin flowing over the surface under the surface and percolating the groundwater and then recharging the stream as groundwater outflow. The river basin runoff is modelled using models; physical analog, statistical, stochastic, black box, through conceptual models. The conceptual models are mathematical models for river basin runoff. Remote sensing technique is employed in conceptual models to provide river basin surface cover and soil information. Remote sensing provides elevation, slope, stream length, channel width and cross sectional details for a river basin. Landuse and surface cover information is provided in remote sensing. The information is interpreted from remote sensing data using element of photo interpretation. The elements of photo interpretation employed are size, shape, pattern, tone, texture and association. Other methods employed are digital techniques in remote sensing to determine land use and surface cover. Both photo interpretation and digital techniques are used for obtaining soil information. Soil is formed by soil forming elements parent material, slope, vegetation, climate and age. The elements are employed to discriminate soils in remote sensing. The land forms are demarcated. Different landforms are formed in unique combination of soil forming factors. A conceptual mathematical model 'Stanford Watershed model' computes interception and upper zone and lower zone storage terms using landcover, slope and depression storage in a basin. The interception is used for open area, grass land and forest land. The upper and lower zone storages are given for land cover, slope and depression storage. The infiltration factor is given in relation to landuse. The interception is of order of one tenths of cm.

Flood Inundation Mapping

With river with smaller cross sections and larger peak discharges results in flooding of plains. Flood inundation are regions subject to inundation in peak discharges. The regions depict high moisture days after recession of floods. The high

soil moisture area are picked up by remote sensing due to signature of the region resembling water signature. The signature of regions is not as low as water reflectance nevertheless in microwave regions the radar back scatter coefficient varies in inverse proportion of soil moisture facilitating demarcation of regions of varying soil moisture. The thermal infrared region images similarly shows signature closely resembling water signature due to high thermal inertial property of high soil moisture regions. The microwave remote sensing has properties of cloud penetration and hence the technique has capability of freezing in time water expanses before, during and immediately after floods. Flood inundation mapping is useful for landuse planning, flood damage assessments.

Groundwater Potential Assessment and Groundwater Targetting

Groundwater potential is related with lithology, weathering, fluvial depositions landforms, slope. The elements are mapped using remote sensing technique and groundwater potential is assessed. The groundwater potential zones of high potential values are places of ground water targetting.

Groundwater and Surface Water Conjunctive Use

The method of groundwater assessment in conjunction of surface water mapping provide potential for conjunctive use protect in water resources. Both mapping is facilitated by remote sensing technique.

GEOGRAPHIC INFORMATION SYSTEM IN PROJECT HYDROLOGY

The applications described earlier and many other application in project hydrology are provided in remote sensing techniques. Geographic Information System (GIS) is an important aid to remote sensing and it deals with remote sensing and other spatial data. GIS is an information system dealing with input, output manipulation and storage of spatial data. Data are input to GIS in binary, text forms or other standard formats. Spatial data are manipulated in GIS using analysis functions such as proximity analysis, corridor analysis. GIS provides a means of overlaying multiple data planes and combining them with different weightages thus providing a means of mathematical computations of information pertaining to a ground parcel. Proximity analysis picks up all the class pixels which are close to or in contact with another class pixels. Corridor analysis picks up classes with specified corridor width. Proximity analysis use can be in making proximity of erosion class to surface water class to

determine contribution of erosion area to surface water directly, to determine proximity of industrial units to surface water. Corridor analysis takes all the areas in a category where a specified corridor is provided. It helps in taking corridors of erosion class, surface water, command area or any other class specified. Overlay analysis helps in combining many planes such as in case of erosion intensity computation from universal soil loss equation computing for each land parcel. The storage of data in GIS allows many information to be stored for applying subsequently required analysis. The information from GIS may be output on display monitor or may be output on paper through many types of printer such as ink jet printer, line printer, thermal printer, laser printer. User interface are provided in GIS such as mouse, simple for use of computer software for greater user friendliness. GIS also does computations such as lengths, areas.

CONCLUSION

Remote sensing is very useful technique due to its synoptic and repetitive coverage of earth surface. The information is also provided in remote sensing at large scale such as upto Scale of 1:50,000 with well developed interpretation techniques and digital techniques, hence its use in project hydrology is an advantage. Information provided from conventional techniques are used together with remote sensing information. The remote sensing deals with spatial data and hence is complemented with GIS a computer based technique for efficient use of remote sensing in project hydrology taking advantage of speed of computer and development in Remote Sensing technology.