DISCHARGE MEASUREMENT OF RIVER TEESTA IN SIKKIM USING

TRACER DILUTION METHOD

A COLLABORATIVE STUDY

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PREFACE

The discharge measurement of mountainous rivers/streams is normally carried out by using conventional methods like float method. Due to the high turbulance and meandering nature of such streams, tracer dilution techniques employing chemicals and dyes as tracers are also used, but with certain limitations. The radioactive tracers have been established as reliable ones, as they provide more accurate information on the discharge of rivers in the mountainous regions.

Sikkim Investigation Division of the Central Water Commision had requested for conducting few experiments on river Teesta to measure the discharge during lean flow period. This was required for correct flow data in connection with installation of microhydels. The National Institute of Hydrology in collaboration with Bhabha Atomic Research Center, Bombay conducted four experiments at different sites on river Teesta in the month of Feb., 1992. The planned second set of experiments could not be carried out due to some unavoidable circumstances.

Dr. S. V. Navada of BARC, Dr. Bhishm kumar and Sh. Rajan vatsa of this Institute, and Sh. A. B. Pandya and his colleagues of CWC participated in the experimental work. This report on 'Discharge measurement of river Teesta using tracer dilution technique' has been prepared by the Scientists of NIH, Roorkee and BARC, Bombay and assistance has been provided by Sh. Rajan Vatsa, SRA and Sh. Rm. P. Nachiappan, SRA.

I hope this report will be useful for the Sikkim Investigations Division of CWC for taking suitable decisions for the installation of microhydels on river Teesta by NHPC.

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CONTENTS

ABSTRACT

Teesta is the largest river in Sikkim with enough potential for the generation of hydroelectric power. At present, the discharge measurements and other related activities are being carried out by Sikkim Investigation Division Gangtok, of Central Water Commission. Keeping in view the potential possibilities of utilization of hydropower to generate electricity, the NHPC has planned to install microhydels at selected sites, but the information about correct discharge is required specially during lean flow period for the purpose of designing the microhydels.

Bromine-82, Tritium, and Potassium Iodide were used as radioactive and chemical tracers. Conventional method using floats was also used for comparison of methods. The results of discharge measurements obtained at four selected sites using different types of tracers and techniques are reported in the table given below.

Site	Discharge (m^3/s)		
	By Float Method	Dilution Method -tritium(T)	Dilution Method -iodide(I-131)
1	2	3	4
1.Chungthang	35	28.5	28.2
2.Sankalang	70	44.3	-
3.Dikchu	85	55.2	54.0
4.Sirwani	110	98.0	-

Comparison of the results obtained by the dilution and float methods show that discharges observed by float method are always higher than those obtained by dilution method. Higher values observed by the float method could be due to whirls and rapids etc.,in the river and effect of wind on the float which decreases the travel time of float. Hence discharge of the river by float method to be checked regularly using the tracer dilution method (iodide or even salt tracer could be tried). Tritium tracer could

be employed twice in a year (in November and in February/March). The amount of potassium iodide injected(3 Kg) at Sirwani was not sufficient and at least twice the amount should be injected(i.e. 6 Kg.) for the discharge measurement.

The higher values obtained in the case of float method at sites Sankalang, Dikchu and Chungthang may be understood with the fact that the float method provides the velocity of the upper layer of the stream which is always higher i.e. the value of stream flow velocity is considered at the depth of 0.6 D for the determination of discharge. In the case of Sirwani, the same values obtained by both the float and tracer dilution methods may be explained keeping in view the prevailing river conditions at the experimental site, i.e. the obstructions due to the big stones in the river and meandering, causing low flow velocity of float.

This study also reveals that the river(Teesta) conditions permits the use of Potassium Iodide as chemical tracer with desired high accuracy.

The details of methodology of tracer dilution techniques and other related aspects are also described in this report.

1.0 INTRODUCTION

The prime function of Hydrology is to provide the 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 present report deals with the various aspects of tracer dilution techniques and experimental work carried out for the measurement of discharge of river Teesta in Sikkim at four sites using tracer dilution techniques and its findings.

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. Tracer dilution techniques require 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 (Tracer dilution 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. 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.

2.0 RIVER TEESTA

Teesta is the largest of the rivers of North Bengal. It rises in the Himalayas in North Sikkim. Running through narrow gorges for nearly 138 km., it debouches into the plains of the Jalpaiguri district at Sivok. Up to this point, its course is Southerly and there after South – Easterly. It flows in a steady course up to Jalpaiguri town beyond which it records frequent changes. It has a number of tributaries, many of them are mountain torrents. The more important of these are the Rangni, the Rangpo, the great Ranjit, the Reli, the Lish, the Gish and the Chel. Draining an area of 12540 sq.km. of which 3,017 sq.km. lies in North Bengal only, it joins the Bramhaputra near Rangpur town in Bangladesh after traversing a length of 309 km.

The river Teesta flows north-south along the length of the state of Sikkim. Being a mountainous river it is an ideal and reliable source of hydropower. For estimating the firm power draft for hydroelectric projects, accurate estimation of lean discharges of the river is necessary. As the river is very turbulent and flows through boulders etc., conventional current meter method is difficult to use. At present, discharge of river Teesta is being measured by using the float method which could give erratic results. Hence for such rivers, the tracer dilution method is most suitable.

3.0 METHODOLOGY

The details of the tracer dilution technique and other related aspects are presented in the following sections.

2

3.1 PRINCIPLE OF TRACER DILUTION METHOD

The basic principle of the dilution method 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 from the injection point at which proper mixing of a tracer with flowing water of a river / stream 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.

3.2 TRACER INJECTION METHODS

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.

3

3.2.1 INSTANTANEOUS INJECTION

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,

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

or $\qquad Q = C_1 V_1 / C (t_2 - t_1) \qquad \qquad \ldots (1)$

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 $\bar{C}$ 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.
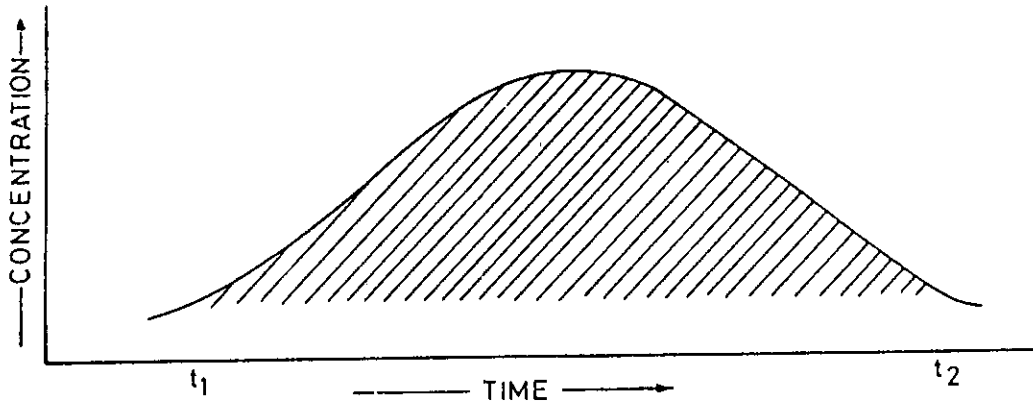

FIG.1 CONCENTRATION OF TRACER ACTIVITY AT GAUGING STATION

Equation -1 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.

4

3.2.2 CONSTANT RATE INJECTION

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, the rate at which the tracer leaves the test reach is $(Q +q)C_2$. Equating these two rates gives the discharge,

$$Q = q \cdot (C_1 - C_2) / (C_2 - C_0) \qquad \ldots (2).$$

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.

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_1, 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_p the duration of the injection must be at least $(T_1 + T_p)$. 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.
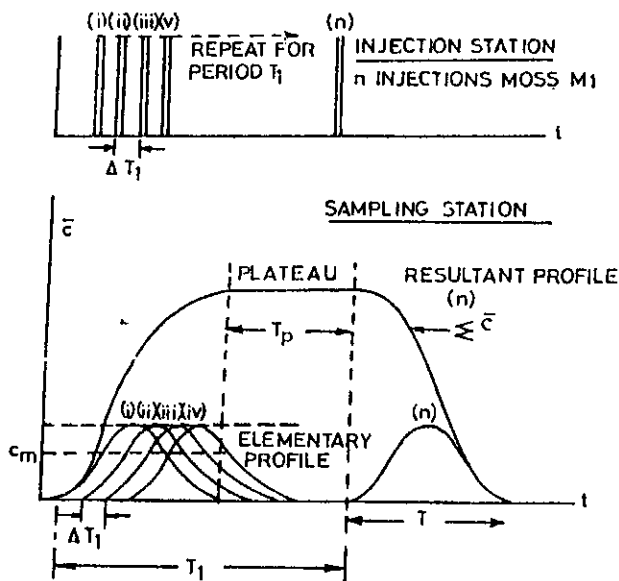

Fig 2 Constant rate injection simulated by repeated
gulp injections show relationship between
plateau duration. T_f and tracer flow through period T

3.3 .TYPES OF TRACERS

Mainly three types of water tracers are used. These are,

   i.   Chemical tracers
  ii.   Dye tracers
 iii.   Radioactive 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 details of main types of tracer in use are described 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 flourimeter 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 photochémical 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.

7

3.3.1 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 slow 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 meter 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 1.86μ 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 μ 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 liter. 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 contains less than $5x10^{-4}$ mg Li/l.
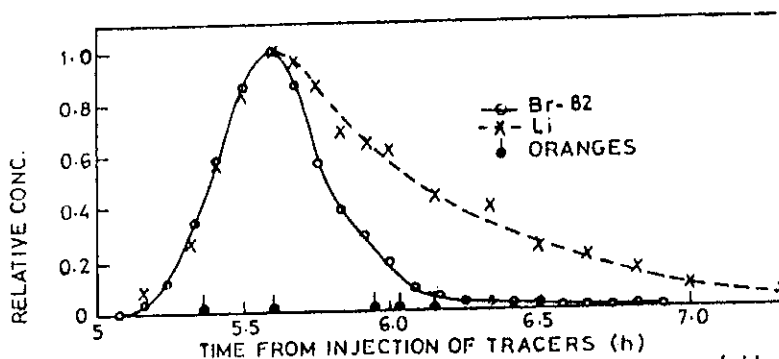
Fig.3 Example of tracer distributions 12 km downstream of the injection of a tracer cocktail

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

10

indicated by the proposed limit for concentrations in drinking water of 0.054 mg/l. It my 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.

3.3.2 Dye Tracers

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 tracer 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 colouring fish flesh. Modern instrumentation

11

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.

3.3.3 Radioactive Tracers

Radioactive tracers are utilized in determining river discharge when extraordinary accuracy is required for the purpose of calibration of other gauging methods.However ,the same can be done with the help of other types of tracers provided they found to be suitable in the prevailing conditions at the river site.

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-lives 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 liter and most isotopes are accurately detectable down to tens of pico curies per liter, 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 liter (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 program 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

13

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 ben 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..

Advantages of using Radioactive tracers:

Some of the advantages of using radioactive tracers over non radioactive tracers are as follows:-

a. Radioactive tracers can be detected in high dilutions of the order 1 part in 10^{12} parts. Hence smaller amount of tracer is sufficient. On the other hand non radioactive tracers have minimum detectable concentration in the range of 1 ppm to 10^{-3} ppm. Hence amount of tracer to be injected is high, causing unacceptable density currents.

b. Radiotracers could be used in highly polluted streams or those with high sediment load. This is generally not possible using non radioactive tracers.

c. Gamma emmiting radioactive tracers could be measured 'in situ' and the results are immediately available. This is not possible with other tracers.

d. Radioactive tracers are particularly useful for high flow rates of the order of 500 m^3/sec.

To summarize, tracers are used on the basis of , 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 tracer, 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.

15

3.4 MIXING LENGTH AND SELECTION OF MEASURING REACH

One important requirement for the tracer dilution method is that the tracer should be well mixed , and the sampling point should be situated at a distance greater than the mixing length from the injection point. A number of empirical formulae are available to evaluate the mixing length.However, as the characteristics of each river could be different , it is better to confirm the mixing length by experiment.

The length of the reach required for satisfactory mixing of tracer with flowing river/stream water is known as mixing length and according to the criteria discussed in the preceding section ,it 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

16

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.

3.4.1 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 .

$$\text{convective period} = 0.3 \; l^2 / \; R \; U^* \qquad \qquad \ldots (3)$$

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 $r(2g\ R_h S)$, where S is the slope of

17

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 x convective period x $\bar{U}_x$ i.e.,

$$L > 1.8 \; l^2 \; \bar{U}x \; / \; R_h \; U^* \qquad \qquad ....(4)$$

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 Keefer (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^3/s at the injections point and 22600 m /s at the lower end of the reach. It was estimated that vertical mixing had ben 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 :

$$L \doteq 0.13 \; b^2 \; C \; (0.7C + 2\sqrt{g})/g \; d \qquad ....(5)$$

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 m^3/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 - 1

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		

19

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	:	$L = 0.032 R^{1/6} B^2 / a_3 n D$
UP IRI formula	:	$L = K B + C$

Where, R is hydraulic radius, a is Manning's coefficient of rogusity, a_1 is a constant - may be taken 50 for centre point injection and 200 for bank injection, a_2 may be taken as between 10 and 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.

3.5 TECHNIQUES OF TRACER INJECTION

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 straight forward. 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 specialized 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 operation 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 dcse 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 $C_1, C_2, .. C_n$ for samples taken across the section; at equally spaced intervals from the mean concentration C .

$$P = 100 \; (1-(C_a-C)+(C_b-C)+... +(C_n-C)) \; / \; n \; C \qquad ....(6)$$

23

Also, in the discussion of the same paper, Ward illustrated the difference between mixing lengths predicted by Fischer's formula (equation 4) and Kimmar'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.

3.5.1   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

24

$$\text{Amax} = (\ 2a\sqrt{\pi kx}\ /\ \sqrt{U}\ )\ (MPC) \qquad\qquad (7)$$

Where,

Amax 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

U   is the mean linear flow velocity

Dispersion coefficient (k) may be estimated by Hull's formula,

$$K = 2.5(Q\ \bar{U})^{1/2} \qquad\qquad \dots.(8)$$

However, according to Guidebook on Nuclear Techniques, 1 to 5 Curies of Tritium is sufficient for flow rate of 100 m^3/sec.

TABLE - 2 : 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, ^{131}I	8.05 days	1.7 to 2.0	2×10^{-5}	Germany India,U.S.A
2.	Bromine, ^{82}Br	35.50 hours	1.7 to 2.0	4×10^{-5}	Germany France,U.S.A
3.	Sodium, ^{24}Na	15.00 hours	1.7 to 2.0	3×10^{-5}	Germany, U.S.A.
4.	Phosph. ^{32}P	14.3 days	—	2×10^{-5}	U.S.A.
5.	Chromium^{51}	27.8 days	—	2×10^{-3}	U.S.A. France
6.	Tritium, ^{3}H	12.5 Years	30.0 to 80.0	3×10^{-3}	India,U.S.A Kenya
7.	Gold, ^{198}Au	64.8 hours	3.0 to 3.5	5×10^{-5}	U.S.A.

** Here the MPC has been referred as minimum possible concentration that can be detected with desired accuracy by the equipment.

3.6 TRACER 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, weds 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.
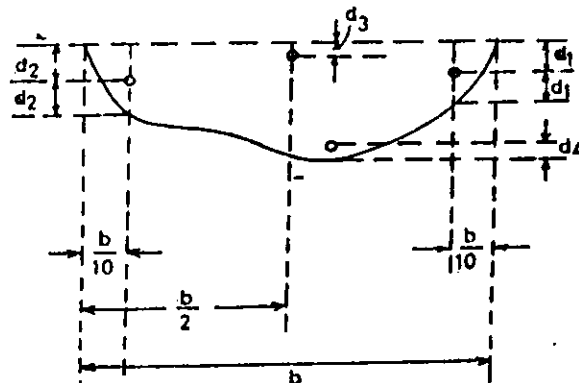

Fig.4 Sampling section defining minimum number of sampling positions for dilution gauging in natural channels

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) ,

27

where it is very easy to calculate the area under the curve. Clearly, as indicated, this idea could be extend 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. 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.
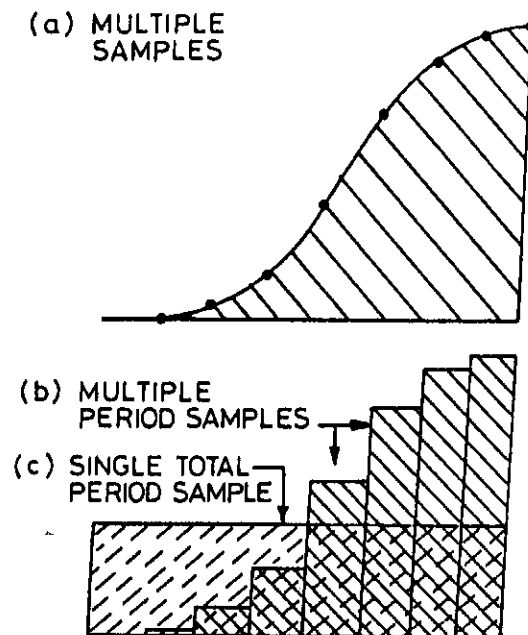

FIG. 5 RESULTANT TRACER CURVE AREAS TO
INTEGRATE FOR THREE SAMPLING TECHNIQUES

28

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 behavior 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 operations,described by White et al (1975).

3.7 PREPARATIONS AND FIELD ACTIVITIES

In most cases it is prudent to spend at least one day in the local area to obtain data on flows, flow frequencies, etc, to get copies of plans and maps, to find out about any past results or experience (e.g. times-of -travel of pollutants) gathered on the river, to asses the nature of the channels and whether ingress or egress of water is likely, to take some rudimentary measurements and photographs to aid planning, to select accessible cross-sections for pilot tests, and to learn of interested parties to be kept informed about the exercise and particularly the use of tracers.

The next stage of preparations, except for small turbulent streams, will be pilot surveys to inspect the river channel in detail in order to select the measuring reacn. A boat or service road travel by a vehicle may be used to serve the purpose depending on the size of the river, but an inspection from road bridges will not suffice as it will not reveal information on inlets, branches, temperature abstractions, and effluents. Maps, however large the scale, do not necessarily provide relevant information and are often out of date. The approximate velocity distribution in a typical cross-section of the measuring reach should be determined and the maximum velocity 'thread' should be located to determine l (equation 5). The hydraulic radius must be estimated from measurements to establish the average width, depth and form of the channel. These activities will enable the shear velocity U and the discharge to be estimated under the prevailing conditions,which should be recorded photographically if stage staff gauges are not available. It may be possible to carry out some preliminary mixing tests and to check the nature of effluents to assess their effect on tracers. Time -of travel estimates can sometimes be obtained using floats (Figure 4), and aerial photography of the behavior of turbid tributaries of effluents can reveal mixing characteristics along the river.

The information gathered allows detailed planning and administrative preparations to proceed. Permission must be obtained to use the tracer and any mixing indicator, such as dye, in the quantities envisaged (Authorization is required by Bhabha Atomic Research Centre Trombay, Bombay for the use of radioactive tracers in India).

The fourth stage to consider is that of the preparations at the laboratory to make up tracer solutions, to check tracer purity, to calibrate injection or sampling equipment, to obtain suitable sample containers and check them for any possible effects on, or interaction with , the tracer at the low concentrations envisaged, to check detection equipment, and to prepare spares ,the quantity of which will depend on how remote the field site is from the laboratory.

30

The next stage is the actual gauging operation and this will start with checks on the degree of similarity of the flow conditions to those existing when the pilot survey was carried out. It is important to establish that the discharge is steady, e.g. by employing portable recording level gauges, and to linage with river management teams to ensure that the gauging will not be upset by the operations of locks, sluices, etc. If the flow is not steady, a decision must be taken on whether to proceed in order to obtain data for future attempts , or to postpone the exercise. It may be necessary to gather flow data for tributaries and weather forecasts to aid this decision. Gilman (1975) showed that serious loss of accuracy will not be incurred by gauging on the recession limb of a hydrograph , but increasing or fluctuating flows may cause considerable errors. It will, of course, still be necessary to prove that mixing conditions are satisfactory and to determine the variation of flow with time in order to assess the tolerance limits for the results using guidelines given in his paper.

The decision on whether to attempt to gauge the flow under prevailing conditions will depend also on the objective, if some discharge information is needed where previously none existed, then it might be worth proceeding even under unsatisfactory conditions, but if the objective is to establish whether a gauging structure is giving correct indications to say +2% , then it would be wise to postpone gauging until the flow is steady.

3.8 ANALYSIS AND ASSESSMENT OF GAUGING ACCURACY

The analysis of samples and field data must be carried out to a degree determined by the success or otherwise of the field operations. The follow up work and the studies at the laboratory, or base , can be very time consuming and therefore costly, and a decision must be taken on whether the samples and information gathered will give an acceptable gauging result or be used to provide mixing and time – of travel data to add the planning or repeat attempts. On completion of the field operations, the following procedure is therefore suggested:

1. Store all samples taken at the sampling stations at a secure place away from possible contamination by

31

concentration stocks of tracer and check that every sample has a secure level showing place, position , time etc.

2. Prepare the analytical equipment and check its operation with laboratory standards.

3. Carry out an approximate analysis on selected samples to establish the time of travel of tracer and the maximum concentrations encountered.

4. Check the background samples to assess their suitability during the period of field measurements.

5. Determine the relative tracer concentrations in the sets of samples to a precision compatible with findings of (3) and (4) above. (several samples should be analysed to check on absolute levels of tracer and the presence of any foreign substance which might interfere with the relative readings.

6. Plot graphs of tracer concentration against time, using the same axes for results applicable to different sampling positions, if possible, critically examine the curves with other data, such as those indicating flow steadiness during the gauging, and assess the efficiency of mixing . Decide whether a valid discharge result can be derived.

7. Use the large-volume back ground samples to make up serial dilutions of the injection solution to about the same concentration as that of the samples. (An alternative procedure that may be used for short-lived radioisotopes is explained below).

8. Report the calculated discharge with the estimated uncertainties as required by national standards.

It is more important to discuss in detail examples of how errors may be caused, than to describe the analysis of samples for various tracers. In any case there are too many tracers to cover and a manual could be written on the detailed precautions for each type of tracer. ' Standard Methods' (American Public Health Association et al., 1975) gives procedures for the determination of the concentration of chemical tracers; in addition, for common salt consult Groat (1915) or Rimmar (1960), and for iodide (where suitable) consult Truesdale and Smith (1975). Smart and Laidlaw (1977) should also prove useful. The literature on radioactive tracers is vast, but an understanding of fundamental concepts for accurate low-level counting may be obtained from the comprehensive laboratory manual prepared by Chase and Rabinowitz (1967) or the text of Watt and Ramsden (1964). An extremely well-prepared and concise general account

of radioactivity measurement is given in an ICRU report (International Committee on Radiation Units and Measurements, 1972).

The first cause of errors is in the determination of volumes and the effect of temperature on both the expansion of solutions and the volumetric capacity of measuring flasks. Even when using the highest grade of glassware, the errors between different operators can be high. It is good practice therefore, whenever possible, and particularly when very accurate gauging is required, to measure all quantities of solution by weight. Modern top-loading electronic balances capable of weighing 1-10 kg quantities to an accuracy of better than 0.01 per cent are available. They are expensive but have a long useful life and form the ideal complement to the accurate balance normally available in chemical laboratories for weights upto about 100g. Use of these balances for serial dilution lessens the chance of spillage and saves time, as only nominal volumes need to be prepared before accurate determination by weighing them. It must be remembered that if all the samples are analysed at a room temperature which is different from the river temperature (e.g. $20^{\circ}C$ and near zero, respectively), then the calculated discharge applies at room temperature and would need to be corrected for the temperature difference unless the result is quoted in gravimetric terms.

Temperature variation may also be a cause of error in the determination of tracer concentrations. An example is the temperature coefficient of fluorescence of the Rhodamine dyes, which is about 3 percent per degree centigrade . It is good practice therefore to let all samples, dilutions, standards and the instrumentation reach a common temperature prior to measurement. It would be possible to list very many temperature effects on detectors, instrumentations components, etc. ,as well as physical , optical and chemical effects on the solutions, and any gauging team must regard temperature variation as a potential enemy, to be kept under surveillance at all times.

Aspects of the measurement of time need considerable attention, not only with regard to cost. Accurate time-of-day

records are essential when records from different sources have to be compared, and accurate determination of time intervals may be of fundamental importance to the gauging, particularly for the constant-rate injection method where the rate of injection is determined at the injection site by taking samples over a short period of time. For the integration method, times of day must be accurate to the desired tolerance. If the timepiece is reading consistently fast or slow, this may not introduce any error in the determination of the area under the tracer curve, so the same timepiece should be handed over on change of sampling personnel. Very seldom do the watches of two persons record exactly the same time even if synchronized at the start of the day. Serious time keeping errors become obvious when the concentrations are plotted and a step occurs in an otherwise smooth curve. Avoidance of such problems is better than correction on the examination of results. For a tracer curve 'p' hours long, time keeping to + 3.6p seconds should keep errors from this cause to less than 0.1 per cent.

In order to calibrate the rates of injection of tracer, problems not unlike those of timing sporting events must be considered. Human reaction times should be assessed and at least two persons may be necessary to determine time periods accurately. One person can operate the controls and one time-piece and the other person can operate two timepieces. If automatic flow-diverter devices are used to collect the sample, then there is the possibility of electronic timing; otherwise the times at which the edge of the sampling orifice crosses the flow must be assessed. Clearly the longer the period of time for sample collection, the lower the proportional error, but a compromise is necessary, particularly with radioactive tracers, because too large a sample may be inconvenient to handle. In most field situations two periods of at least 100s will be necessary, both at the beginning and end of a constant- rate injection, to provide data from which to assess the injection rate and its tolerance accurately. Electronic timers sometimes record repeatable units of wrong duration, and devices relying on the frequency of the electricity supply for timing should be checked for errors.

The next source of error to consider is concerned with the mixing process in making up serial dilutions. Groat (1915) gave a guideline when he carried out some tests to track down apparent sources of error. He found that an ordinary stopper liter flask with a long neck, about 1.5 cm in diameter, required from 25 to 30 double inversions, with time for the air to rise to the surface in each position, in order to secure a uniform mixture of 10 ml of nearly saturated salt solution with about 990 ml of distilled water. At the Water Research Centre it has been found that the addition of diluent to the flask last, or the use of magnetic or air-bubble stirring techniques, can help the process. Again , the critical procedure is to carry out the operations in duplicate or triplicate, i.e. repeats of the serial dilutions to assess both systematic and random errors. If there is little urgency for results, magnetic stirrers can be used to advantage to mix each dilution more thoroughly overnight. Also, if time is available when short-lived radioactive tracers are used, it is possible to utilize the physical decay of the isotope instead of dilution (for Bromine-82 a 100-fold decrease in concentration takes 235h) and the compromise can only be assessed by careful consideration of the errors involved in both processes. The purity of the isotope should be checked and the decay of one sample checked over the decay period used.

Groat (1915) presented tables, graphs and numerical examples to correct for the volumetric shrinkage that occurs when two salt solutions of differing densities are mixed. Although this effect may be trivial in particular cases, it should be included (but has not been in this account)in rigorous presentations of the basic dilution gauging equations and when calculating the values of comparative dilutions.

If considerable quantities of chemicals are used , the total amount of tracer to be used for one injection should be taken from the same supply batch whenever possible. Systematic errors may arise because of differences in the chemical composition of the salt used. As an example, the readings of flame photometers used to determine Lithium will depend on the concentration of other substances present. When the concentrations of tracer in the samples have been found they should be plotted, as shown

35

in Figure 5(a) with the analytical error bars. At this stage , one or two results may look doubtful and the samples can then be re-read. Obvious 'flyers' which may be caused by cross contamination are also eliminated from the results at this stage. The remaining results, to be used to compute the flow, are averaged for the constant-rate method or used to calculate the area under the curve in the integration method. The area may be found using a technique compatible with the accuracy desired of the gauging, i.e. by counting squares, measuring areas cut from graph paper, by use of a planimeter, or by numerical methods with the aid of a computer. Computer techniques are extremely valuable when short -lived radioactive tracers are used because decay corrections may be carried out as part of the computation. Another advantage is that where the results show that some tracer was still passing when sampling stopped, the area under the falling limb of the curve can be extrapolated using the last few results . Some pocket calculators are capable of performing this task, and when such predictions are necessary it is convenient to end the integration when the predicted concentration reaches three standard deviation above the mean background level. Florkowski et al (1969), using tritiated water as the tracer, have shown experimentally in a number of rivers that the falling limb of tracer curves is very close to exponential form and that the extrapolation of the curve will cover an area a where

$$a_t = c_t \ t_{1/2} \ /0.693 \qquad \qquad ....(9)$$

c_t is the concentration of the last sample , and $t_{1/2}$ is the half time of the concentration decay read from the linear portion of a semi logarithmic plot of the falling limb of the tracer curve.

When dilution gauging results are compared with discharge results produced by other methods such as weirs and flumes, it must be remembered that dilution methods determine the flow of water only and this may not be the same as the flow of fluid along the channel. The fluid comprises the diluted water and suspended solids. In some parts of the world, rivers can often contain very high loads of sediment. Beverage and Culbetrson

36

(1964)have given examples where the flow consists of over 40 per cent suspended solids;they also suggest that the degree of mixing may be considerably reduced as the suspended solids loading is increased. These considerations are of little concern if the quantity of water, as a resource, is being evaluated but clearly the density and composition of the fluid will be important when comparing data.

It was pointed out that a fundamental requirement for dilution gauging is that flow is steady. If the discharge should change appreciably during the measurement, systematic positive or negative errors will occur because of the change in storage volume and retention time of elements of water in the measuring reach. The magnitude of the errors has ben calculated by Gilman (1975) judging residence - time distribution models. The errors was found to be least when the discharge varies smoothly and slowly, as on the recession limb of the hydrograph, and when the mean transit time between the injection and sampling cross- sections is least. This latter finding implies advantage in minimizing the mixing distance at those sites where unsteady flows are probable . The data gathered during the field work from gauging stations and stage readings along the reach should be examined to assess the degree of steadiness of flow before, at, and following the time of gauging. Gilman's work may then, if necessary, be used to estimate the errors. Similar errors will be caused if the storage volume in the reach changes for any other reasons.

It is important that the background sample should be representative of the background concentration of tracer during the gauging. A change in discharge may be accompanied by a change in the background concentration, or in collaboration, which may be interpreted by the method of analysis as a change in the tracer concentration (colorimetric analysis is especially prone to this type of interference). Any apparent change in the colour or sediment load of the stream with time should be noted, and repeat background samples taken.

3.9 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.

4.0 EXPERIMENTAL WORK CARRIED OUT

It was informed by the Sikkim Investigation Division of CWC that National Hydroelectric Power Corporation has to establish micro hydel power stations on river Teesta , therefore , the correct information about the discharge of river Teesta during lean flow period is required at the desired sites for the proper designing of the micro hydels. The lean flow is observed in river Teesta mainly during the period from December to March.Therefore ,it was decided to conduct the first set of experiments in the month of December 91 and the second set of experiments in the month of Feb. 92 .But, due to some problems ,the experimental work could not be carried out in the month of Dec. 91.Hence , the experimental work was carried out in the month of Feb. 92 with the active involvement of scientists namely, Dr.S.V. Navada ,U.P.Kulkarni and G.H.Mendekar of Hydrology and Tracer Section of Isotope Division, Bhabha Atomic Research Centre, Bombay.

4.1 SELECTION OF SITES

At the request of CWC Gangtok, according to the need of NHPC, radiotracer experiments were carried out to measure the discharge of the river at 4 pre decided sites along the river,in collaboration with BARC ,Bombay . However the suitability of the sites , as per details given below were ensured according to the criteria described in the preceding sections.

a. Stage III Dam site at Chungthang
b. Stage IV Dam site at Sankalong
c. Stretch between stage IV power house and 14th Mile bridge at Dikchu and
d. Stretch between Dipudara and Sirwani

The radiotracer investigations were carried out between 15th February and 22nd February, 1992.

The mixing length (L) in the present study was computed using both Andre's and Hull's formulae:

$$L = a\ b\ Q^{1/3} \quad \text{(Andre's)} \qquad\qquad L = a_1\ Q^{1/3} \quad \text{(Hull's)}$$

where a = 10, a_1 = 200 (for bank

       b = 20m and   injection)
                Q = expected flow rate of the river.

The mixing lengths computed for the 4 sites are as follows:-

TABLE - 3

Site	Expected flow rate (m^3/s)	Mixing length (m)	
		Andre's	Hull's
Chungthang	35	650	650
Sankalong	70	820	820
Dikchu	85	870	870
Sirwani	110	960	960

The location of these sites along with the part of river Teesta is shown in figure 7 .

TRACERS USED AND QUANTITY OF TRACERS

Bromine 82, gamma ray source was used at site Chungthang as tracer to find out the mixing length, to access the utility of the various empirical formulae and to have the discharge result at site for the comparison with the results being obtained using conventional technique.

Br-82 of specific activity 186 mci/cc, total 372 mci was obtained from BARC, Bombay. This activity was mixed with 9 liters of water and injected with the constant rate injection device as shown in fig. 2, at site Chungthang of river Teesta. The injection took about 22 minutes at the rate of 262 cc. per minute.

Two sets of Scalar rate meter with detector(gamma ray detection device) were placed at a distance of 500 m and 700 m

from injection point at right bank sites. Both the Andre's and Hull's formulae were used for estimating the mixing length, the results of which were identical. In another experiment conducted at site Chungthang, Tritium (1 curie) and Potassium iodide (1.5 kg) were used as tracers.

Similarly at sites Mangan, Dikchu and Sirwani, experiments were carried out using Tritium and Potassium iodide as tracers.

4.2 WATER SAMPLING WORK.

The sampling was carried out along the river at all selected sites except at site Chungthang where the sampling at left bank was not feasible. The water samples were collected in 20 CC airtight plastic containers with the help of remote operated device and brought to the laboratory for analysis of the tracer concentration.

4.3 ANALYSIS OF TRACER ACTIVITY

The samples were analysed for Potassium iodide concentration with the help of Spectrophotometer at H & T Section laboratory at BARC, Bombay. The Tritium activity was also analysed at BARC Bombay with the help of liquid scintillation counter and standard solution of liquid scintillator available in the market. The analysis work was carried out by the scientists of BARC, Bombay.

4.4 TRACER INJECTION AND RESULTS:

The tracer was injected at a constant rate using a constant head device and a peristaltic pump. The re-producibility of tracer injection rate was better than 0.5% in repeated measurements.

In Chungthang site ^{82}Br tracer was used to check the mixing length. This was followed with ^{3}H and inactive Iodide tracers. In Sankalong only tritium tracer was used. In Dikchu and Sirwani both tritium as well as iodide tracers were used.

The tracer was first mixed in a known amount of water in a bucket and an aliquot of injection solution was taken for determining the initial conc. Co. The tracers were injected for a fixed duration of a time ranging for 30 min to 60 minutes.

40

The ^{82}Br injection was made to examine the proper mixing length required and to find out the duration of the concentration plateau. About 11 GBq (300 mCi) of ^{82}Br was taken in about 8 litres of water and injected at a constant rate for a period of 30 minutes.

At distance of 600 m and 800 m downstream from the injection point, water proof NaI (TL) scintillation detectors were kept immersed in water and connected to rate meter/scaler to monitor the passage of the tracer. The count rates obtained have been plotted against time and shown in Fig.8 and 9. At the plateau water samples were collected and counts determined. As the count rate obtained at 600 m was adequate. The duration of the concentration plateau was about 15 minutes.

Tritium and Iodide Tracers:

About 11 GBq (300 mCi) of ^{3}H as tritiated water and 1 Kg of Potassium iodide were used for the injection. Duration of injection was about 45 minutes. The sampling station was 800 m from the injection point.

The tritium concentration obtained are as follows:-

TABLE - 4

Sr. No.	Sample identity	Sampling time (Hrs.)	Tritium count rate (Net) cpm
1.	1	9.42	23
2.	4	9.51	67
3.	6	10.00	70
4.	10	10.10	72
5.	12	10.14	72
6.	15	10.20	63
7.	17	10.24	18
8.	22	10.34	9
9.	26	10.45	11

$$\text{Hence } Q = \frac{216 \times 570 \times 10^6}{60 \times 72 \times 10^6} = 28.5 \text{ m}^3/\text{s}$$

41

Iodide Tracer:

The final concentration = 0.0147 μg/ml   and

initial concentration   = 0.115 μg/ml

$$Q = \frac{216 \times 0.115 \times 10^6}{60 \times 0.0147 \times 10^6} = 28.5 \ m^3/s$$

Sankalong

Tritium Tracer:

. About 150 GBq (4 Ci) of ^{3}H as tritiated water was used for
the injection. Duration of the injection was about 30 minutes.
The expected discharge of the river was 70 m^3/sec. The sampling
stations were kept at 1 km and 1.5 km respectively. Sampling was
done at both the banks of the river.

The results of samples collected at 1.5 Km have been
presented in table -5.

TABLE - 5

Sr. No.	Sample No.	Time of sample collection	Net Tritium Conc.(cpm)	
			Left Bank	Right Bank
1.	1	11.00	34.9	31.7
2.	3	11.10	58.8	47.6
3.	4	11.15	60.9	50.6
4.	5	11.20	65.6	51.9
5.	6	11.25	45.6	68.4
6.	7	11.30	52.7	61.0
7.	8	11.35	59.9	63.6

The Net tritium count rate Vs sampling time has been shown in
fig.10 . However no clear plateau is observed in fig.10.The final
tritium concentration was selected when the count rates at the
plateau showed same value at both the banks = 61.8 cpm.

Initial tritium concentration = 776 x 10^6 cpm/m^3

$$\text{Hence, } Q = \frac{216 \times 776 \times 10^6}{60 \times 61.8 \times 10^6} = 44.3 \ m^3/s$$

Dikchu:

About 185 GBq (5 Ci) of ^{3}H and 2 Kg of potassium iodide were used for the injection. Duration of the injection of 45 minutes. Expected discharge of the river was 85 m^3/sec. The sampling stations were kept at 1.5 km and 2 km respectively from the injection point.

Tritium Results:

The results of the samples collected at 2 km has been presented in table 6.

TABLE - 6

Sr. No.	Sample No.	Time of sample collection	Net Tritium count rate(cpm)	
			Left Bank	Right Bank
1.	1	1340	16	18.3
2.	3	1350	14.5	24.6
3.	5	1400	42.4	35.5
4.	6	1405	48.3	40.0
5.	7	1410	78.3	50.1
6.	8	1415	61	55
7.	9	1420	52	58

The net count rate Vs sampling time (Fig.11)shows a smooth rise of tritium concentration with time with plateau starting from 14.15 Hrs. The final concentration of tritium was taken as 55 cpm which was mean count rate at 1420 for both the banks.

The initial tritium concentration was 844×10^6 cpm/m^3

$$\text{Hence, } Q = \frac{216}{60} \cdot \frac{844 \times 10^6}{55 \times 10^6} = 55.2 \ m^3/s$$

Iodide:

The initial iodide concentration was 0.14×10^6 $\mu g/ml$ and the final concentration was 0.009 $\mu g/ml$

$$\text{Hence, } Q = \frac{216}{60} \cdot \frac{844 \times 10^6}{55 \times 10^6} = 56 \ m^3/s$$

<u>Sirwani</u>:

About 220 GBq (6 Ci) of ^{3}H and 3 Kg of Potassium iodide were used for the injection. Duration of the injection 60 minutes. Expected discharge of the river 110 m^3/sec. The sampling station were keep at 2 km and 2.5 km from the injection point.

Tritium Tracer

The tritium results of the samples collected at station at 2.5 Km from injection point has been presented in Table - 7.

TABLE - 7

Sr. No.	Sample No.	Time	Net Tritium count rate(cpm)	
			Left Bank	Right Bank
1.	1	1320	7.5	7.8
2.	2	1330	7.7	7.0
3.	4	1345	10.2	5.2
4.	5	1352	5.6	11.5
5.	6	1400	11.9	13.5
6.	8	1415	23.6	27.3

The tritium conc. Vs time plot has been presented in Fig.12 .From the figure final tritium conc. was 30 cpm and initial conc. was 828×10^6 cpm.

$$\text{Hence, } Q = \frac{216}{60} \cdot \frac{828 \times 10^6}{30 \times 10^6} = 98 \ m^3/s$$

The iodide tracer could not be applied as the final iodide conc. was below the detection limit.

5.0 DISCHARGE MEASUREMENT USING FLOAT

During experimental work of discharge measurement of river Teesta,using tracer dilution technique, conventional technique using wooden floats and balloons were also used to determine the discharge values for comparison purposes. It is important to disclose here that Sikkim investigation Division of Central Water Commission used the Wooden float to determine the discharge of river Teesta at the selected sites and in general the same method is also being used for other mountainous rivers.

Results obtained at the 4 sites:

The results obtained at the 4 sites by the tritium and iodide tracer methods have been presented in Table - 8.

TABLE - 8

Site	By Float Method	Dilution method -tritium	Dilution method -iodide
1	2	3	4
1. Chungthang	35	28.5	28.2
2. Sankalang	70	44.3	-
3. Dikchu	85	55.2	54
4. Sirwani	110	98.0	-

6.0 ERRORS IN MEASUREMENT

The relative error in the determination of the discharge of the river Q can be given as

$$\frac{\sigma(Q)}{Q} = \sqrt{\frac{(\sigma q)^2}{q} + \frac{(\sigma c)^2}{(c)} + \frac{(\sigma co)^2}{(co)}}$$

This is true assuring the complete mixing of the tracer before reaching the sampling point. The relative error is <1% with proper precautions.

The degree of imperfect mixing is usually the main source of error. In the case of constant rate injection method, the % of imperfectness of mixing =

$$\frac{100}{nC} \quad \sum_{1}^{n} \quad c - c$$

where n is no. of sampling points in a given cross section. The degree of imperfectness in mixing has been computed for Sankalang and Dikchu sites.

Sankalang:

Net cpm in left bank   = 59.9 cpm (C1)
Net cpm in the right bank = 63.6 cpm (C2)

Hence, C = 61.8 cpm

$$X = \frac{100}{n\,C} \sum_{1}^{n} c_i - C = \frac{100}{2 \times 61.8} \quad 3.7$$

= 3.0%

Dikchu

Net cpm in left bank = 65.6 cpm (C1)
Net cpm in right bank = 63.3 cpm (C2)

Hence , C = 64.5 cpm

$$X = \frac{100}{n\,C} \sum_{1}^{n} c_i - C = \frac{100}{2 \times 64.5} \quad (2.3)$$

7.0   CONCLUSION

Comparison of the results obtained by the dilution and float methods show that discharges observed by float method are always higher than that obtained by dilution method. Higher values observed by the float method could be because of whirls, rapids, etc. in the river and effect of wind on the float which decreases the travel time of float. Hence discharge of the river by float method to be checked regularly using the tracer dilution method (iodide or even salt tracer could be tried), Tritium tracer could be employed twice in a year (in November and in February/March). The amount of potassium iodide injected (3 Kg) at Sirwani was not sufficient and at least twice the amount should be injected (i.e. 6 Kg) for the discharge measured.

The results of discharge of river Teesta for the four selected sites obtained using Tritium as tracer and float method are given in table-1. It can be clearly seen from table – 1 that the discharge values obtained at site Chungthang using Tritium as tracer and float method are almost same while for other sites the float method values are higher.

The higher values obtained in the case of float method at sites Sankalong, Dikchu and Sirwani may be understood with the fact that the float method provides the velocity of the upper layer of the stream which is always higher i.e. the value of stream flow velocity is considered at the depth of 0.6 D for the determination of discharge .

46

In the case of Sirwani, almost comparable values of discharge obtained in both cases may be explained keeping in view the river conditions prevailed at the experimental site,i.e. the obstructions of the big stones in the river and meandering caused the low flow velocity of float.

This study also reveals that the river (Teesta) conditions permits the use of Potassium Iodide as chemical tracer with desired high accuracy.

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