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Discharge Measurement of River Teesta in Sikkim Using Tracer Dilution Technique

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Abstract

River Teesta is a perennial river with substantial flow even in lean season. It flows in North-South direction along the length of the state of Sikkim and forms the single major river in the state drawing water from 95% of the total area of the state.

There is a programme to install micro hydels on this river. The information about the flow rates of river during the lean period was required for designing the microhydels .The discharge of river Teesta was measured at four sites viz. Chungthang, Mangan(Sanklang), Dikchu and Sirwani using tracer dilution technique. These sites were chosen according to the proposed programme for the installation of microhydels.

Methodology, details of the experimental work carried out and the results are discussed in this paper. The discharge values obtained using conventional techniques at different sites are 40% to 50% higher than those obtained by tracer dilution technique except at site Chungthang.

INTRODUCTION

Dilution techniques, are used where conventional methods of flow measurement of rivers and streams are not suitable due to higher degree of turbulance . These 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. British Standards Institute(1967,1974,) and International Organisation for Standardization(1973,1974,1978) have brought out number of publications on measurement of discharge of streams using dilution techniques. Mainly, three types of tracers are employed for measuring low flows using dilution techniuqes _

(i) Chemical tracer

(ii) Fluorescent dyes

(iii)Radioactive tracer,
Generally two types of radio active tracers are used _

Tracers emitting gamma rays - having short half life,

Tracers emitting soft beta rays - having comparatively longer half life.

The choice of radioactive or non-radioactive tracer depends upon the regulations in force in the country concerned. In most of the cases, permission from the national radiation protection body are required for field use of radioisotopes as tracer. As far as radiological safety aspects are concerned, no major problems are encountered in the application of radioactive tracers.

Radioactive tracers are used in cases where specific requirement insists to do so(Joly, J.,1977), for example-

Measurement in highly polluted water where the use of other tracers is limited (White, K.E, et al ,1976).

Measurement in water with a high suspended sediment concentration.

Cases where continuous recording of the flow rates is necessary.

High discharge upto 5ØØ cumecs are to be measured (Florkowsi T.,et al 1969).

If conditions permit, non radioactive tracers should be prefered. In general, the detection sensitivity of tracer dilution should not be very far than permissible concentration in water.

Radioisotopes generally used in the measurement of discharge of streams are given in table-1.

Table 1 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 $\mu Ci/cm^3$	Countries where used
1.	Iodine, I-131	8.Ø5 days	1.7 to 2.o	2×10^{-5}	Germany, India, U.S.A.
2.	Bromine, Br-82	35.5 hours	1.7 to 2.Ø	4×10^{-5}	Germany, France, U.S.A
3.	Sodium, Na-24	15.Ø hours	1.7 to 2.Ø	3×10^{-5}	Germany, U.S.A.
4.	Phosphorus P-32	14.3 days	-	2×10^{-5}	U.S.A.
5.	Chromium, Cr-51	27.8 days	-	2×10^{-3}	U.S.A.& France
6.	Tritium, H-3	12.5 Years	3Ø.Ø to 8Ø.Ø	3×10^{-3}	India, U.S.A., Kenya
7.	Gold, Au-198	64.8 hours	3.Ø to 3.5	5×10^{-5}	U.S.A.

PRINCIPLE

The basic principle of the dilution technique is to mix a suitable tracer with flowing water at a point and to observe its dilution at some other appropriate distance after its homogeneous mixing with river/stream water. It should be noted that the principle of the technique will be valid only if_

(1) The tracer is not lost on the way and it has the flow characteristics near to water.

(2) There is no inlet or outlet for the river/stream water in between the injection and sampling point.

(3) The sampling is carried out after the proper mixing of tracer with flowing river/stream water.

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 concerntration c_2 is establihsed 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. The rate at which the tracer leaves the test reach is $(Q + q)c_2$

Equating these two rates-

$$Q = q.(c_1 - c_2)/(c_2 - c_0)$$

or if $c_1 >> c_2$ and $c_2 >> c_0$ then,

$$Q = q.c_1/c_2$$

In the integration method of dilution gauging, a quantity of tracer of volume V1 and concentration c_1 is often added to the river, simply by pouring 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 calcualted from the equation

$$M_1 = c_1 V_1 = Q \int_{t_1}^{t_2} (c_2 - c_0)dt = Q.A$$

or

$$Q = c_1 V_1 / \bar{c}\,(t_2 - t_1) \quad ; \quad \bar{c} = A/(t_2 - t_1)$$

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.

SELECTION OF MEASURING REACH

The length of the reach required for satisfactory mixing of the tracer with stream/river water (known as mixing length), can be many kilometers . The dispersion coefficient of tracer should not change along the reach between the cross-sections used for the injection of tracer and for sampling (Fischer ,H.B. 1967; Fscher ,H.B, 1968; Bansal ,M.K., 1971; Day ,.T.J. 1975). The measuring reach should therefore be of similar form and nature over the whole of its length. There should be no ingress of water along the measuring reach because such an occurence 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. Similarly there should be no outlet also in the measuring reach.

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.

Empirical Formulae for Measuring Reach

Few empirical formulae are 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 : $L = \text{Ø.ØØ32 } R^{1/6} B^{2} / a_3 n D$

U . P . I . R . I . formula : $L = K B + C$

Fisher formula $L > 1.8 I^{2} \bar{U}_x / R_h U^*$

Rimmar's formula: $L = \text{Ø.13 } B^{2} C'(\text{Ø.7}C' + 2\sqrt{g})/g\, d$

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 15 to 5Ø for rough to smooth bed conditions. R_h is hydraulic radius, a is Manning's coefficient of rugosity, a_1 is a constant and can be taken 5Ø for centre point injection and 2ØØ for bank side injection, a_2 may be taken 27 for small stream with centre point injection, a_3 may be taken from Ø.3 to Ø.8, C and K are constants, K is 77 for bank side injection and constant C is equal to 1ØØ as determined experimentaly and U^* is the shear velocity ($\sqrt{2gR_h S}$), where S is the slope of the water level, g is acceleration due to gravity and $\bar{U}x$ is the mean velocity. The other notations have their usual meanings.

TRACER INJECTION TECHNIQUES

Generally two techniques are used for the injection of tracer into the stream-

(i) Constant rate injection technique,
(ii) Instantaneous injection technique

The principles of these techniques have been described in the preceeding section. The equipment/device used for the injection of tracer at constant rate is shown in fig. 1. Salient features of injection technique and precautions to be taken during injection are mentioned below _

In the instantaneous injection method, the injection procedure is straight forward but sampling programme must be exact.

In the constant rate injection method, the injection procedure must be exact, but, sampling programme should be straight forward.

In instantaneous injection method - duration of injection is unimportant, but to reduce the chance of density and tracer concentration at one point extended injection is preferable.

It is important to ensure that the quantity injected can be accurately deduced from initial and final measurements.

It is worth while taking some precautions against loss of tracer. For this purpose - preliminary experiments can be conducted using weak dye solution or other chemicals.

Convenient type of apparatus can be used to inject tracers, depending upon the quantity and concentration.

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 at site.

Injection rate must be measured at the begining and end of period of injection and considerable skill is required to carry out these operations.

Tracer solution to be injected should be prepared in laboratory alongwith checking of tracer purity, calibration of injection and sampling equipment.

Equipment to be used for detection in the field should be checked in the laboratory.

At the time of actual gauging operation, it is important to check that the discharge is steady by employing a portable recording level gauge.

If steady discharge is not possible, the decision should be taken whether to postpone the experiment or it is possible to consider the effect of fluctuations (Gilman. K. ,1975).

Tracer can be injected at the banks or in the middle of the stream or simultaneously at banks and in middle also.

In most of the cases single tracer release outlet near mid stream is choosen but, it is not essential.

Multi point injection reduces the mixing length 'L' drsatically.
N-points of injection will reduce the mixing length N times.

A twin injection technique might reduce 'L' by a factor of 4 and for similar reasons, 'L' should be about 4 times greater for a bank injection in comparision to mid stream injection.

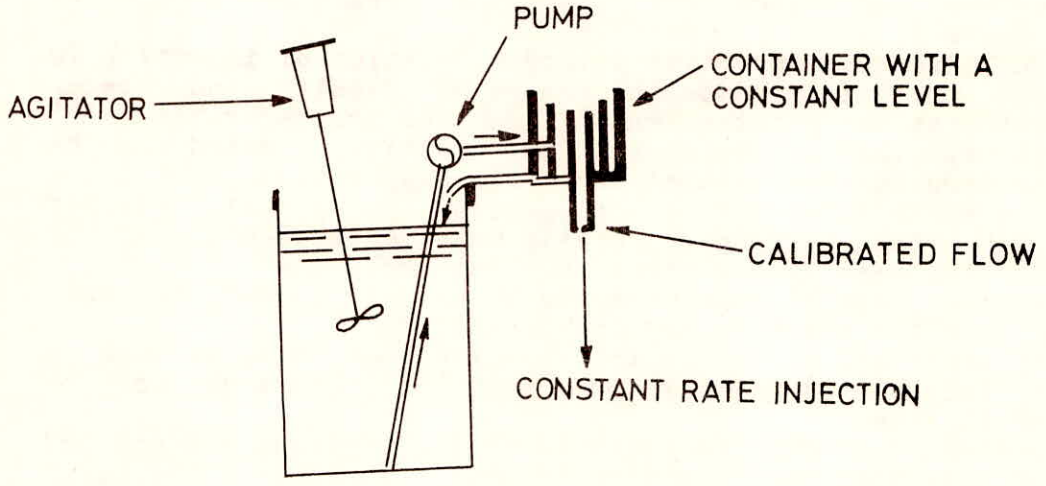

FIG. 1- CONSTANT RATE INJECTION DEVICE

Reach having manderings and obstacles will have lesser 'L' in comparision to a smooth reach.

QUANTITY OF RADIOACTIVE TRACER

The quantity of radioactive tracer used should be minimum for radiological safety considerations. However 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_

$$Amax = [\ 2a\sqrt{\pi kx}\ \sqrt{\bar{U}}\ ]\ (ALI)$$

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
ALI is the annual limit of irradiation
U is the mean linear flow velocity
Dispersion coefficient (k) may be estimated by Hull's formula

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

However, according to Nuclear Guidebook 1 to 5 curies of Tritium is sufficient for flow rate of 100 m /sec.

SAMPLING PROCEDURE

The procedure for sampling depends upon the degree of accuracy required. 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. A single sampling point can suffice but should, in general, be regarded as inadequate. 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.

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.

The problem is to decide when to start and end the 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 sampling 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.

PREPARATIONS AND FIELD ACTIVITIES

Generally, it is essential to spend at least one day in the local area to obtain data on flows, flow frequencies, to find out about any past results or experience gathered on the river, to asses the nature of the channels and whether ingress or eggress of water is likely, to take some rudimentary measurements and photographs to aid planning, and to select accessible cross-sections. 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 mixing length. The hydraulic radius must be estimated from measurements to establish the average width, depth and form of the channel. Time-of travel estimates can be obtained using floats.

CAUSES OF ERRORS

The first cause of errors is in the determination of volume 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. 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 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.

Aspects of the measurement of time need considerable attention. Accurate time-of-day records are essential when these 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.

The next source of error to consider is concerned with the mixing process in making up serial dilutions. Groat (1915) presented tables, graphs and to correct for the volumetric shrinkage that occurs when two salt solutions of differing densities are mixed.

If considerable quantities of chemicals are used, the total amount of trcer to be used for one injection should be taken from the same suply batch whenever possible. Systematic errors may arise because of differences in the chemical composition of the salt used.

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.

Experimental Work Carried Out

Lachen Chu and Lachung Chu are two streams meeting at Chungthang (at the height of 16ØØ metres). From the point of confluence onwards the resulting stream is known as Teesta which is a perenial river with substaintial flow even in lean season.It is the major river of Sikkim that flows North-South along the state.

River Teesta is an ideal source of hydropower generation because of enormous fall of the order of 36ØØ metres over a river stretch of 175 kilometres.

Although data for high flow flood discharge are very important ,the low flow observations are also equally important for the estimation of firm power draft for hydel power projects.It is necessary to have accurate lean flow data.

At present 12 gauging sites are being maintained by Sikkim Investigation Division (SID) of Central Water Commission (CWC), over Teesta river upto Sirwani. The observations of flow so far are being made by conventional methods only. The float method is mostly used for the measurement of discharge .Hence the chances of erroneous results of discharge are very high. SID of CWC therefore proposed National Institute of Hydrology (NIH), Roorkee for taking up the work of flow measurement of Teesta river using the radio-isotopes . The study was carried out by Bhabha Atomic Research Centre (BARC), Bombay and NIH ,Roorkee jointly.

SELECTION OF SITE:

Keeping in view the points described above and requirements of NHPC to install the microhydels following four sites were selected at river Teesta _

1. Chungthang
2. Sanklang
3. Dikchu
4. Sirwani

The location of these sites at river Teesta is shown in figure-2 .

TRACERS USED AND INJECTION OF TRACER:

Bromine-82, a gamma ray emitter was used at site Chungthang

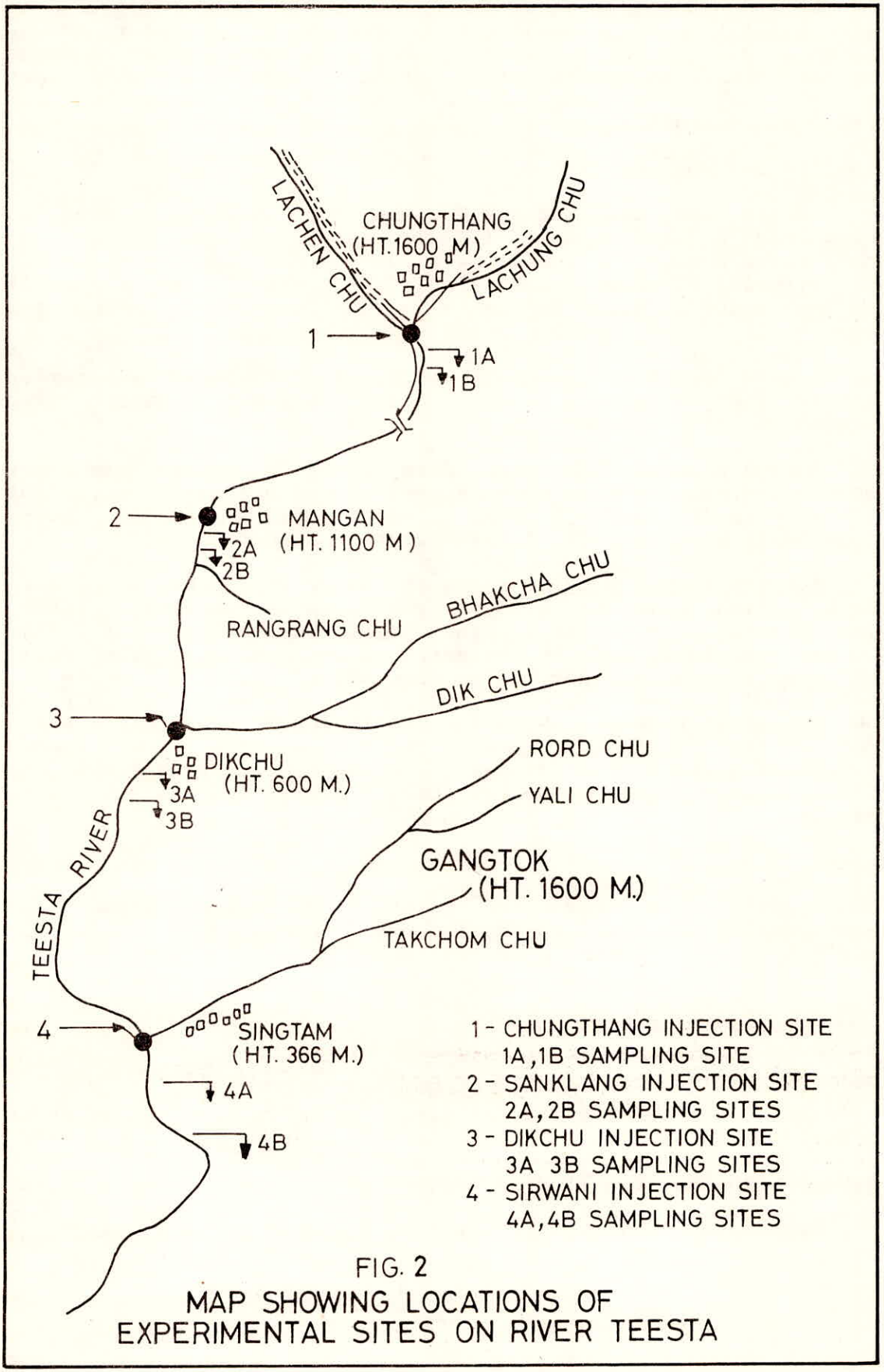

FIG. 2

MAP SHOWING LOCATIONS OF EXPERIMENTAL SITES ON RIVER TEESTA

as radioactive tracer to find out the mixing length, to assess the utility of various empirical formulae and to have the discharge results at site for comparision with the results obtained using conventional technique.

Total 372 mCi of Br-82 ,having specific activity 186 mCi/cc, 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.-1 , at site Chungthang of river Teesta. The injection was made at the rate of 450 cc per minute and it took 20 minutes for injecting 9 litres of tracer solution.

Two sets of Scaler rate meter with detector (a gamma ray detection device) were placed at a distance of 500 m and 700 m at right bank of river Teesta . The Hull's formula was used for estimating the mixing length. In an other experiment conducted at site Chungthang, Tritium (radioactive tracer, 1 Curie) and Potassium iodide (chemical tracer, 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.

SAMPLING WORK.

The samples were collected mostly from both the banks of river at all 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 and brought to the laboratory for analysis of the tracer concentration.

ANALYSIS OF TRACER ACTIVITY

The samples were analysed for Potassium iodide concentration with the help of ion analyzer at the water quality laboratory, of NIH, Roorkee. The Ttritium activity was analysed at BARC, Bombay and at Univ.of Roorkee, Roorkee, with the help of liquid scintillation counter using standard solution of liquid scintillator available in the market.

DISCHARGE MEASUREMENT USING CONVENTIONAL TECHNIQUE

During experimental work of flow measurement of river Teesta, by tracer dilution technique, conventional technique using wooden floats and baloons was also tried to determine the discharge values for comparision .It is important to mention here that SID of CWC is presently using the wooden floats to determine the discharge of river Teesta at the selected sites and in general the same method is adopted by other divisions also, of CWC .

RESULTS AND DISCUSSION

The results of discharge of river Teesta for the four

selected sites obtained using Tritium as tracer and float method are given in table-2 . The results of discharge using Potassium iodide as chemical tracer, are not reported in this paper as the data could not be obtained properly and hence not analysed.

It can be clearly seen from table 2 that the discharge values obtained at site Chungthang using Tritium as tracer and float method are almost same while the float method values at Mangan and Dikchu are 50 -55 % and at Sirwani 13% higher in comparision to the results obtained using tracer dilution technique.

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

In the case of Chungthang,the similarity in discharge values, obtained in both the cases may be explained on the basis of river conditions prevailed at the experimental site,i.e. presence of boulders in the river flow path and manderings, reduced the velocity of float.

Table 2 DISCHARGE VALUES OBTAINED AT RIVER TEESTA

Site	By Tracer Dilution Technique	By Conventional Technique
CHUNGTHANG	1034 cusec	1059 cusec
SANKLANG	1612 cusec	2506 cusec
DIKCHU	1908 cusec	2506 cusec
SIRWANI	3440 cusec	3916 cusec

Acknowledgement

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REFERENCES

1. Bansal, M.K.,1971.Dispersion in natural streams, J. Hydr. Div. Am.Soc.Civ. Engrs, 97 (HY11), 1867-1886.

2. British Standards Institution, 1967. Methods of measurement of liquid flow in open channel:Part 2, Dilution methods; 2C,London (revised version at advanced stage of preparation as ISO 555\111).

3. British Standards Institutioin, 1974. Methods of measurement of liquid flow in open channels:part 2, Dilution methods ;2A, Constant-rate injection, BS 368Ø; Part 2 A London.

4. Cole, J.A.,1969. Dilution gauging by inorganic tracer; notably the plateau method using dichromates, Symposium on River Flow Measurement held at Loughborough University of Technology, (1Ø-11 September),Institution of Water Engineers,London.

5. Day,T.J.,1975.Longitudinal dispersion in natural channels. Wat. Resour. Res.,11,9Ø9-918.

6. Fisher,H.B.,1967. The mechanics of dispersion in natural streams, J.hydr. Div. Am. Soc.civ.Engrs,94(HY6)187-216.

7. Fisher,H.B.1968. Dispersion predictions in natural streams, J.saint. Engng Div. Am. Soc.civ. Engrs,94(SA5),927-943.

8. Florkowski, T., Davis, T.G., Wallander, B. abd Prabhakar, D.R.L.,(1969), The measurement of high discharges in the turbulent rivers using Tritium tracer, J.Hydrol.,8, 249-264.

9. Gilman.K.,1975. Application of a residence-time model to dilution gauging with particular reference to the problem of changing discharge, Bull IAHF, 2Ø,523-537.

1Ø. International Atomic Energy Agency,1968. Guidebook on nuclear techniques in hydrology. Tech.Rep.Ser. No.91,IAEA, Viena.

11. International Organization for Standardization, 1973. Liquid flow measurement in open channels; Dilution methods for measurement of steady flow; Constant-rate injection method,ISO: 555 I, Switzerland.

12. International Organization for Standardization, 1974. Liquid flow measurement in open channels; Dilution methods for measurement of steady flow, Part II, Integration (sudden injection) method, ISO: 555 II, Switzerland (revised version under preparation).

13. International Organization for Standardization, 1978. Liquid flow measurement in open channels, Vocabulary and symbols, ISO,772, Switzerland.

14. Joly, J., 1977. On a new method of gauging the discharge of rivers, Proc. R.Soc., Dublin, 16,489-491.

15. White, K.E., Belcher, A.S.B. and Lee, P.J., 1975. Absolute flow measurements to obtain depth against discharge for sewers using Bromine-82 and Lithium as tracers, Conference on Fluid Flow Measurements in the Mid-197Øs, National Engng Lab.,Glasgow.

DISCUSSION

G.C. MISHRA, (NIH ,Roorkee) : How the parameter 'a', in Hull's formula has been found ? Have the concentration variation with time has been found ? If so the variation be shown.

AUTHOR(S) : 1. Hull's has specified that the value of constant 'a should be taken "50" for tracer injection made in the center of the river and '200' if the tracer has been injected at the bank.

2. The variation of concentration of tracer with time has been plotted and will be shown to Dr. G.C. Mishra later on in his office.

H.B. SATISH KUMAR (Karnataka Power Corporation Ltd.,Bangalore) : The discharge measurements by float method are consistently higher than those obtained by tracer techniques. One of the probable reasons is that the surface velocity are higher than the velocities at lower depths . usually the mean velocity over the depth is about 0.6 to 0.7 of that of maximum velocity. Consequently this charge measurements by float method given higher discharges. These aspects may be clarified.

AUTHOR(S) : The reason behind the high values obtained using float method is only one which has been described by Sh. H. B. Satish Kumar. There may not be any other reason for getting high values, because, the other parameters associated with flood, like higher density, and its flow, like obstacles and turbulence, will reduce the velocity of flow of float and ultimately, the value of discharge should be at lower side.