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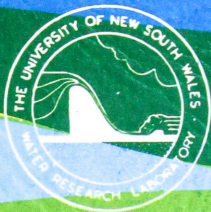
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THE UNIVERSITY OF NEW SOUTH WALES

# water research laboratory

Manly Vale, N.S.W., Australia

**Report No. 117**

## **CHEMICAL GAUGING OF STREAMFLOW**

**by**

**F. C. Bell**

**December, 1969**

University of New South Wales  
WATER RESEARCH LABORATORY

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P r e f a c e .

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The work was mainly carried out by Mr. F.C. Bell, after some preliminary work by Mr. S.J. Perrens. The project was supervised at various times by Mr. C.R. Dudgeon, Mr. V.J. Summersby, Associate Professor E.M. Laurenson and Dr. D.H. Pilgrim. Other members of the staff of the Hydrology Section and Water Research Laboratory assisted in the project.

H.R. Vallentine,  
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(ii)

### Summary.

Chemical dilution methods of stream gauging with sodium dichromate ( $\text{Na}_2\text{CrO}_7 \cdot 2\text{H}_2\text{O}$ ) were tested in a tilted laboratory flume for flows up to 5 c.f.s. and at various locations on a range of natural streams for flows up to 210 c.f.s. Accurate check calculations of flow were available with the flume tests and these indicated probable errors of  $\pm 4.5\%$  for the constant injection method. In turbulent sections of natural streams this method was found to have about the same accuracy as current meter gaugings under ordinary flow conditions although successful applications required careful attention to details that are readily overlooked. Similar orders of accuracy were obtained with the sudden injection method but this method required extra laboratory work and an inconveniently large number of samples. It was concluded that the constant injection chemical gauging technique with sodium dichromate is a useful ancillary method with special advantages over current meters in certain circumstances. However, it does not appear to be superior to the current meter method when reasonable conditions for the latter are available.

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## CHEMICAL GAUGING OF STREAMFLOW

### 1. INTRODUCTION

Although chemical dilution methods of stream-gauging have been known for at least a century, their general use has not been favoured by organizations responsible for the collection of hydrologic data. Some of the reasons for this appear to be as follows:

- (a) measurements by current meter seem to involve less time and trouble,
- (b) in the past, little was known about the reliability of chemical gaugings,
- (c) the sodium chloride (common salt) used in early investigations could not be measured accurately in very small concentrations and inconveniently large amounts were therefore required for the flows of major interest\*.

In recent years, however, there has been an upsurge of interest in chemical gauging following successful tests with various chemicals that may be accurately measured in small concentrations. These include sodium dichromate ( $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ ), radioactive isotopes and fluorescent compounds such as rhodamine B and pontacyl pink.

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\* It should be noted, however, that dilution gaugings with sodium chloride have occasionally proved very useful for measuring flows in certain circumstances. Typical of such cases were a series of measurements carried out by the State Electricity Commission of Victoria at Kiewa in 1956-60 which are described briefly in section 2.5.

H. Andre<sup>(1)</sup>, of the French Electricity Commission has contributed notably to the development of practical techniques with sodium dichromate. This chemical is now used to a considerable extent for routine flow measurements of turbulent mountain streams in France, Switzerland and other European countries<sup>(3)</sup>. Similar techniques with radioactive and fluorescent materials are topics of intensive investigation at the present time in the United States of America, Australia and elsewhere.

The Water Conservation and Irrigation Commission of New South Wales and the Water Research Foundation of Australia have provided research grants to the University of New South Wales for a study of chemical gauging with sodium dichromate under Australian conditions. The results and findings of that study are presented in this report.

## 2. BASIC PRINCIPLES OF CHEMICAL GAUGING

### 2.1 Constant Rate of Injection Method

The chemical is injected at a constant rate into a stream and after an appropriate time has elapsed, samples of the stream water are taken at a downstream point where the chemical has become thoroughly mixed over the entire cross section. The degree of dilution of the chemical at this point is related to the stream discharge in accordance with equation (1).

$$\frac{Q}{q} = \frac{C_1 - C_2}{C_2 - C_0} \quad \dots\dots\dots (1)$$

where  $Q$  = rate of flow of the stream  
 $q$  = rate of injection  
 $C_0$  = concentration of the chemical occurring naturally in the stream water



$C_1$  = concentration of chemical in injection fluid  
 $C_2$  = concentration of chemical in stream at  
 sampling point.

In most cases  $C_0$  is negligibly small compared with  $C_2$ , and  $C_2$  is negligibly small compared with  $C_1$ , so equation (1) may be reduced to equation (2).

$$\frac{Q}{q} = \frac{C_1}{C_2} \quad \dots\dots \quad \dots\dots \quad (2)$$

Thus, the discharge of the stream may be calculated if the rate of injection  $q$  and the concentrations  $C_0$ ,  $C_1$  and  $C_2$  are known. For equations (1) and (2) to be valid it is important that sufficient time be allowed for relatively steady concentrations to develop at the sampling point as shown in Figure 1.

## 2.2 Sudden Injection Method

An alternative method is to release instantaneously a known volume of the chemical into the stream. Downstream samples are then taken at regular intervals of time to enable an accurate determination of the concentration-time relationship which has the form of a "pulse" curve as shown in Fig.1. The stream discharge is related to the concentration-time curve by equation (3).

$$Q = \frac{V(C_1 - C_2)}{\int_0^T (C_2 - C_0) dt} \approx \frac{VC_1}{\int_0^T C_2 dt} \quad \dots\dots \quad (3)$$

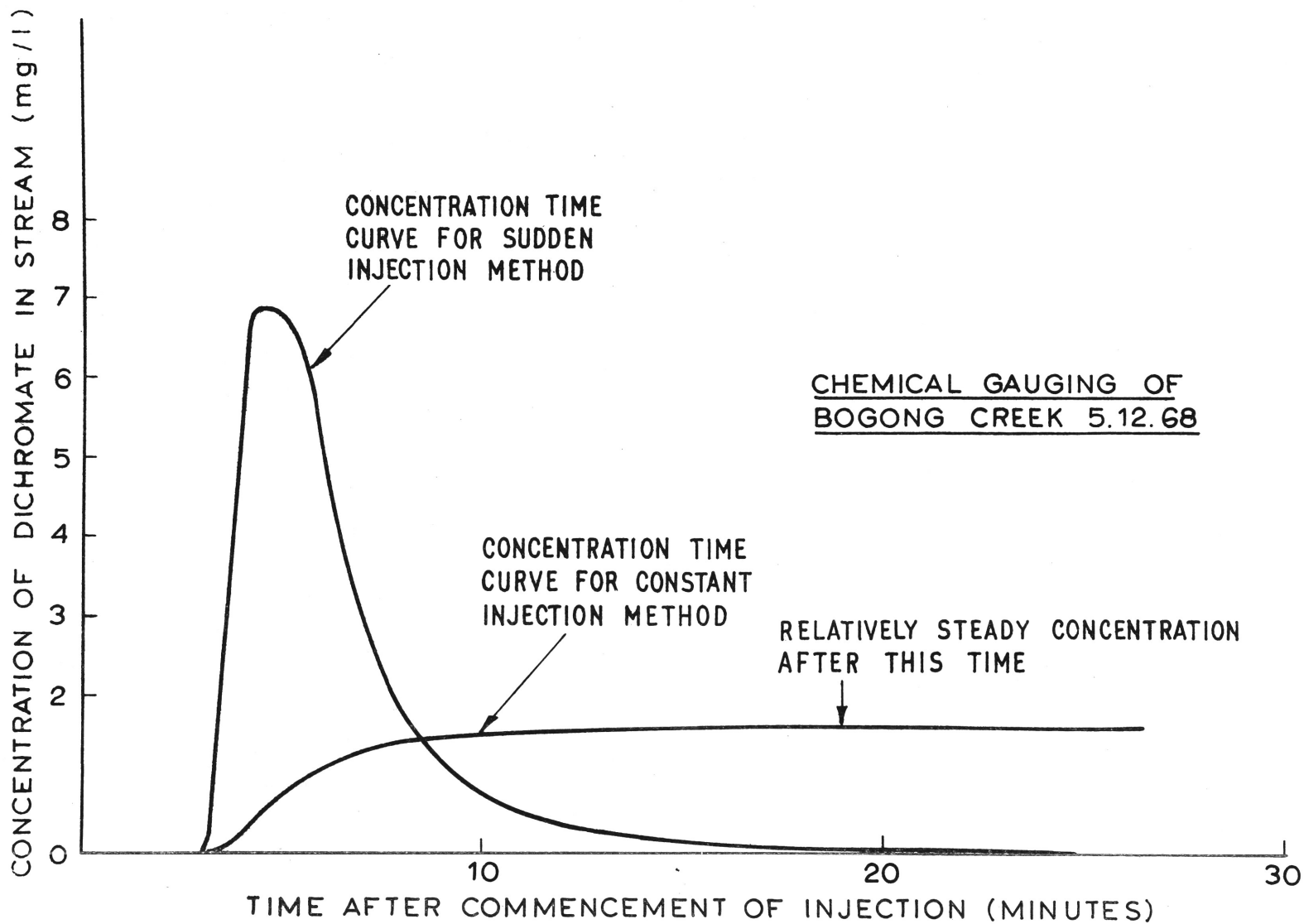


FIG.1: TYPICAL CONCENTRATION - TIME CURVES

where  $Q$  = rate of flow of the stream (cfs)  
 $C_0$ ,  $C_1$  and  $C_2$  are concentrations of the  
 chemical as for equations (1) and  
 (2).

$V$  = volume of injected chemical ( $\text{ft}^3$ )

$T$  = time (secs) for  $C_2 - C_0$  to become  
 insignificantly small

$\int_0^T C_2 dt$  represents the area under the  
 concentration-time curve as shown in  
 Fig.1.

Theoretically it is possible to evaluate  $\int_0^T C dt$  if equal volumes of stream samples are taken at equal time intervals during the passage of the pulse and bulked into a single container. The concentration of this bulked sample multiplied by the sampling time is equal to the area of the concentration-time curve. However, this procedure does not permit the operator to check on whether the frequency and period of sampling are adequate and it is therefore not usually recommended.

### 2.3 Estimation of Mixing Length and Sampling Duration

Equations (1) to (3) are valid only if the distance between the injection point and sampling point are sufficient to ensure a relatively uniform concentration of chemical throughout the stream cross section at the sampling point. The minimum distance for this condition is called the "mixing length" and its estimation at the start of a gauging is an important step in the procedure.

The British Standards Institution<sup>(2)</sup> and the (British) Water Research Association recommend the following

formula due to Rimmar<sup>(4),(5)</sup> for estimating mixing length:

$$L = \frac{0.13 W^2 C(0.7C + 11)}{gD} \approx \frac{.004 W^2 C^2}{D} \approx \frac{.004 W^2 V^2}{D^2 S} \quad (4)$$

where L = mixing length (ft.) with concentration of solution uniform to within 1%.

W = average width of water surface (ft.) downstream of injection point.

D = average depth of water downstream of injection point (ft.).

C = Chezy roughness coefficient in FPS units. It may vary from about 25 for very turbulent flow to about 90 for smooth, uniform flow.

V = estimated average velocity downstream of injection point (ft/sec).

S = slope of water surface (ft/ft.).

g = acceleration due to gravity  $\approx 32$  ft/sec/sec.

Equation (4) applies when there is a single injection point in the centre of the stream. The mixing length is greater if the injection point is near the bank and it is smaller if there are several injection points. However, there is some controversy concerning the extent to which these variations affect the mixing length, as discussed in some detail by Barsby<sup>(4)</sup>.

Several other formulae for estimating mixing length have been proposed by various investigators. These include the following:

D.E. Hull's Formulae<sup>(6)</sup>

$$L = 3 W \sqrt{\frac{W}{D}} \quad \dots\dots\dots (5)$$

$$L = a_1 Q^{0.33} \quad \dots\dots\dots (6)$$

H. Andre's Formula<sup>(3)</sup>

$$L = a_2 W Q^{0.33} \quad \dots\dots\dots (7)$$

N. Yotsukura's Formula<sup>(3),(7)</sup>

$$L = \frac{.032 R^{\frac{1}{6}} W^2}{a_3 n D} \quad \dots\dots\dots (8)$$

where L, W and D are the same as for equation (4).

Q = estimated discharge (cfs).

R = hydraulic radius (ft).

n = Manning roughness coefficient.

$a_1 \approx 150$  for centre-point injection.

$\approx 600$  for bank-side injection.

$a_2 \approx 27$  for small streams with centre-point injection.

$a_3$  = a coefficient which Yotsukura has found to vary from 0.3 to 0.8.

According to Barsby's investigations,<sup>(4)</sup> equations (5) to (7) are less reliable than Rimmar's formula. With regard to equation (8), there does not appear to be



sufficient information available to date to permit the determination of coefficient  $a_3$  and it is therefore not yet possible to assess the reliability of this equation.

Although Rimmar's formula is apparently the most satisfactory of the above equations, it can give no better than a rough estimate of the mixing length in many circumstances<sup>(2)</sup>. It is desirable, therefore, to check the uniformity of mixing at the selected site either by observation of dye dispersion (e.g. fluorescein dye) or by sampling at a number of points across the stream section.

The British Standards Institution suggests that observations of dye dispersion may be used also for estimating the duration of sampling. Obviously, the constant injection method is not valid if the sampling is completed before sufficient time has elapsed for relatively steady concentrations of chemical to develop in the mixing reach. Similarly, the sudden injection method cannot give reliable results unless the duration of sampling is sufficient to enable the proper determination of the concentration-time curve. Unfortunately, no satisfactory formulae for estimating the sampling duration from the stream characteristics appear to be available.

## 2.4 Injection and Sampling Apparatus

The constant rate injection apparatus shown in Figs. 2 and 3 is recommended by the Office Federal de l'Economie Hydraulique, Switzerland, and also by H. Andre of Division Technique Generale de la Production Hydraulique d'Electricite de France. In this apparatus the constant head tank is fed through a control valve and filter from a 40 gallon header tank. As shown in Fig. 3 the solution

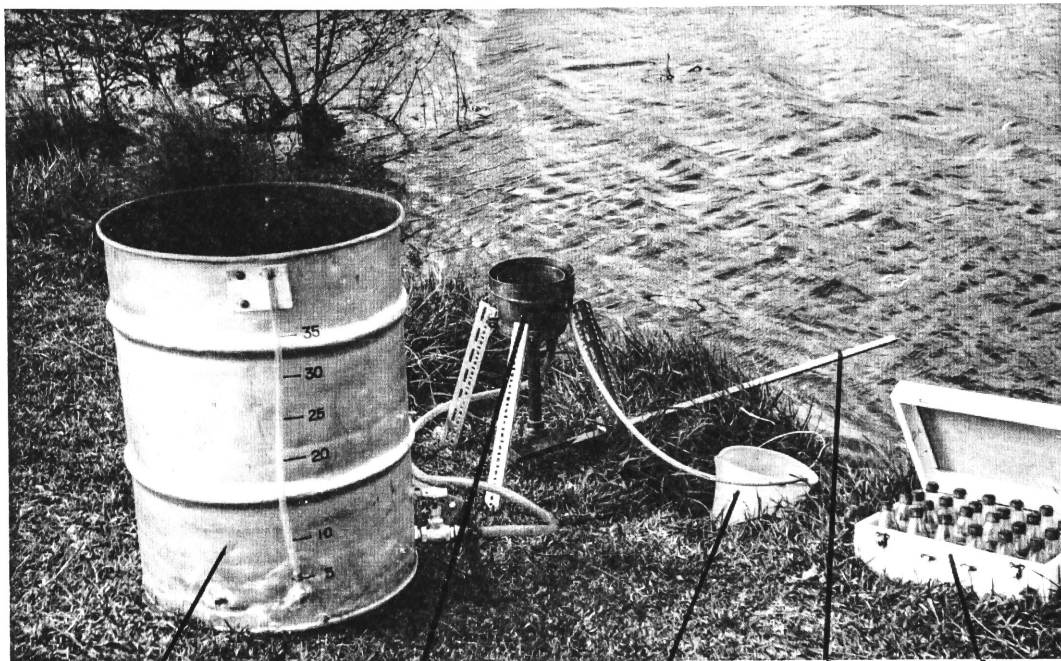
passes upward through a perforated grate into the main chamber of the constant head tank and the excess overflows at the top. This excess is collected in a bucket and returned to the header tank from time to time.

The orifice at the base of the constant head vessel can be readily removed for cleaning or for interchanging with other orifices of different size. It is therefore possible to obtain a large range of injection flow rates. The orifice discharges either directly into the stream or into a collector funnel which feeds into a distribution pipe. This distribution pipe is mounted over the stream, permitting the simultaneous injection at a number of points.

A simple mariotte vessel, as shown in Fig.4, is suitable for injecting fluids at a constant rate. In this device the effective head of fluid above the nozzle outlet is kept at the constant value  $H$  in Fig.4 because atmospheric pressure is maintained in the fluid at the end of the air inlet pipe. The weight of the column of fluid above this level is balanced by the reduced pressure of the air trapped at the top of the vessel. The injection rate may be changed by altering the nozzle size or the distance  $H$ .

The British Standards Institution suggests that a constant rate of injection may be obtained from a rotary volumetric pump driven by a constant speed motor. The Institution also describes a floating siphon device for the same purpose<sup>(2)</sup>.

One of the advantages of the sudden injection method is that no special apparatus is required to deliver the chemical to the stream. After the volume of injection



Header Tank

Constant Head Vessel

Overflow Bucket

Injection Trough

Sampling Bottles

Fig. 2: 40-Gallon Constant-Head Injection Apparatus.

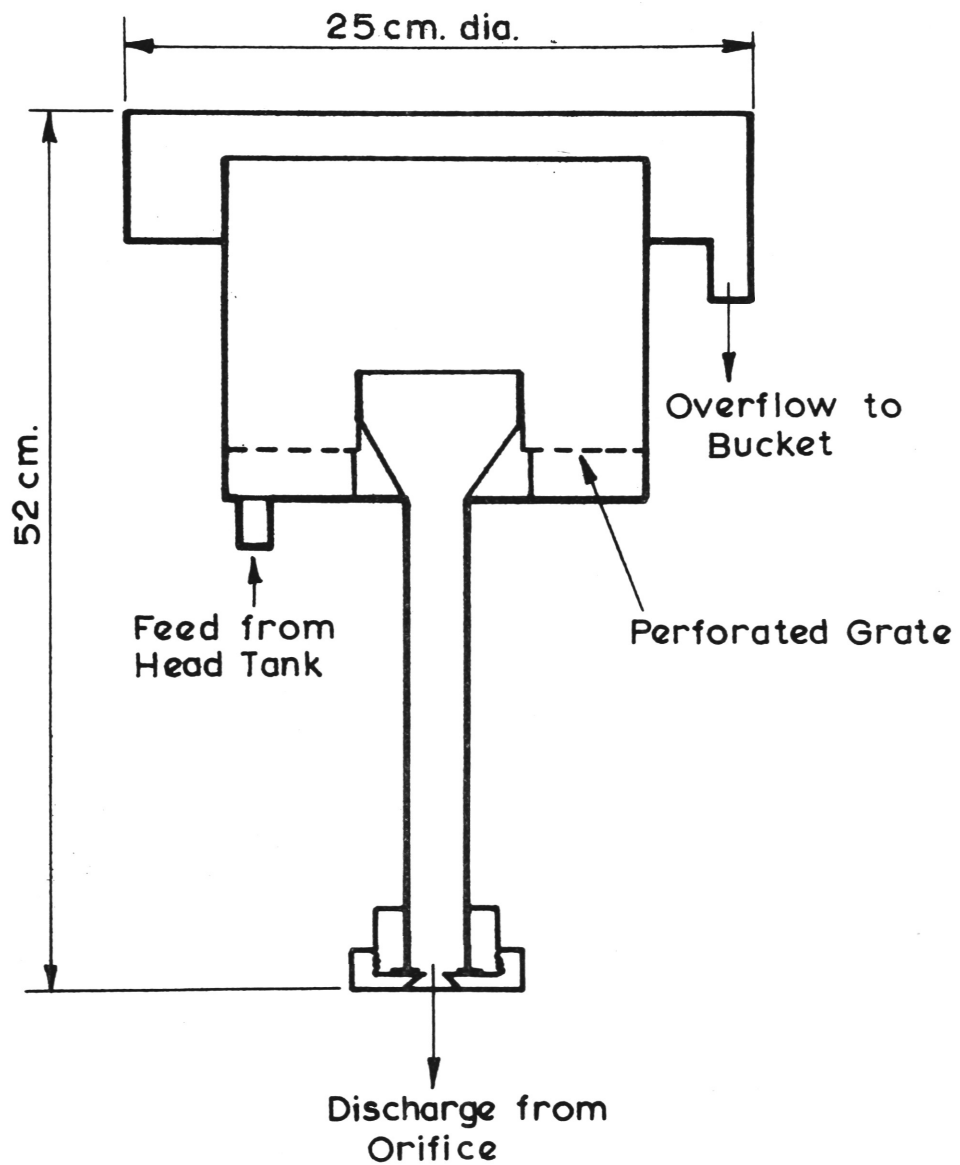


FIG. 3 : SECTION THROUGH CONSTANT-HEAD VESSEL

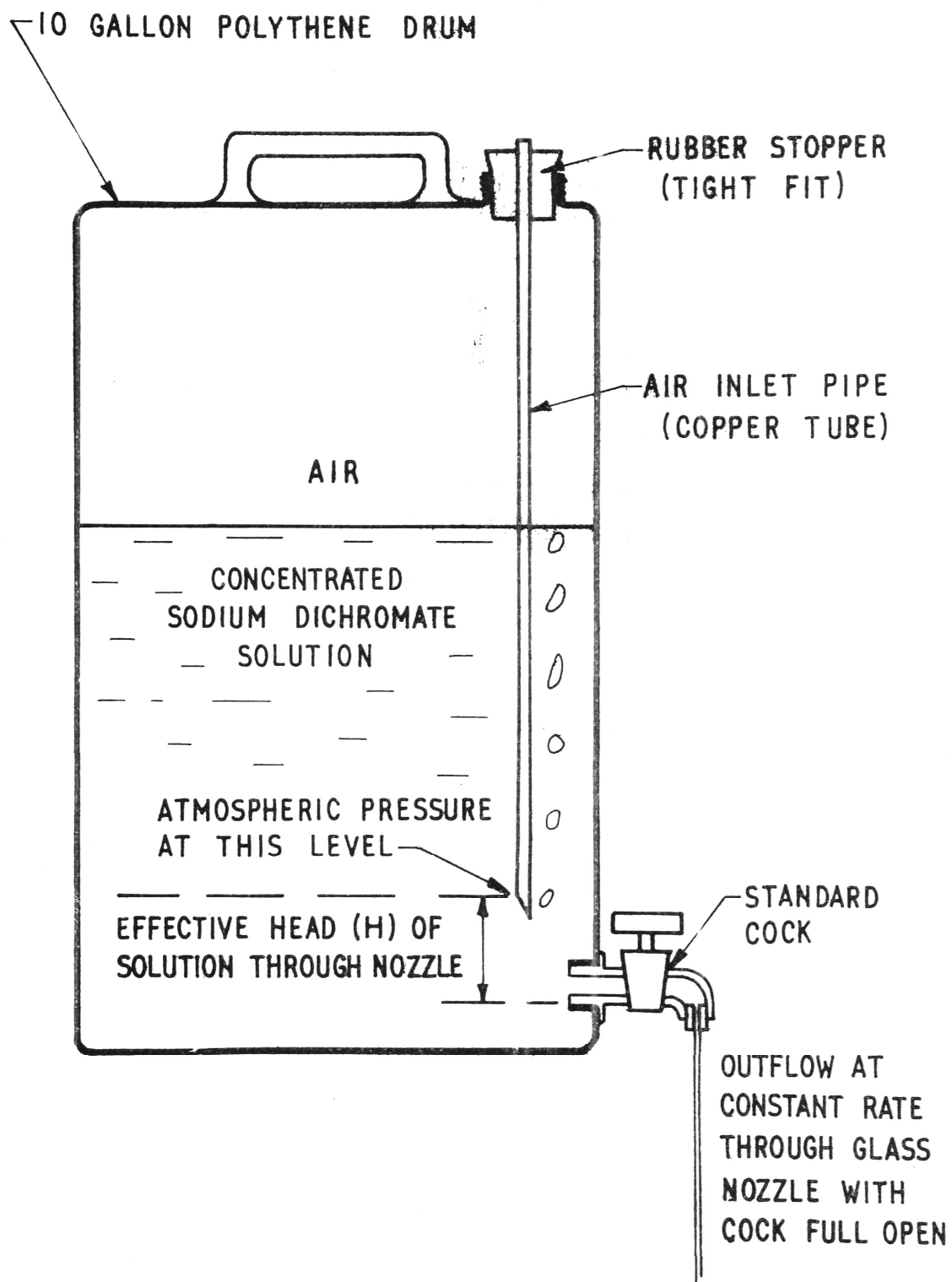


FIG. 4: MARIOTTE VESSEL



fluid has been accurately measured, any bucket or similar container may be used, providing it enables the full volume of fluid to be released immediately.

Glass bottles with rubber or glass stoppers are generally recommended for the collection and transport of stream samples. Plastic or polythene bottles tend to absorb some of the chemical and may result in the contamination of other samples if used again. Cork stoppers also have this disadvantage.

The cleanliness of the injection and sampling apparatus is an extremely important aspect of the procedure. A very slight contamination of a stream sample by a small residual of chemical from a previous gauging is generally sufficient to completely invalidate the results.

## 2.5 Suitable Chemicals and their Measurement

Theoretically, it is possible to measure stream-flow by dilution methods with any material having the following properties:

- (a) readily miscible with water,
- (b) capable of accurate measurement at low concentrations in water,
- (c) not unduly absorbed or changed by the stream environment.

Sodium dichromate ( $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ ) has all of these properties and, in addition, is relatively inexpensive, the cost per lb. being approximately 40c. (Australia, 1969). It is measured in low concentrations by colorimetric analysis with either a colorimeter or spectrophotometer.

In the colorimetric analysis of a stream sample containing sodium dichromate, 2.5 ml of diphenylcarbazide ( $(C_6H_5NH.NH)_2CO$ ) are added to 50 ml of the stream sample giving a reaction with a reddish-violet colour which reaches a maximum intensity after a period of about 10 minutes. This intensity remains constant for a further 15 or 20 minutes and then commences to fade slowly. The maximum intensity of colour is proportional to the amount of chromate present and may be measured in a spectrophotometer or colorimeter by the percentage of light transmitted through a standard sample at a wavelength of 540 mμ<sup>(8),(9)</sup>.

Depending on the type of spectrophotometer or colorimeter used, it is generally possible to obtain accurate measurements of dichromate concentrations as low as .05 to .20 mg/l (mg/l are equivalent to ppm.). Because sodium dichromate is poisonous, water authorities in a number of countries have specified allowable upper limits of its concentration in public water supplies and these are in the vicinity of .05 mg/l.<sup>(9)</sup>

Sodium dichromate has no chemical reaction with natural water but it is slowly reduced by organic agents in the water, especially in the presence of light. It is therefore unsuitable for gauging the flows of highly polluted streams unless the samples are re-oxidized by boiling with silver nitrate and ammonium persulphate. For normal, unpolluted streams dichromate is not usually affected significantly by reduction if the samples are kept in the dark and analysed within one or two days after the gauging.

Potassium dichromate is evidently a suitable alternative to sodium dichromate as it has the same type of reaction with diphenylcarbazide and its concentrations may

be measured down to the same low values.

Other chemicals that may be measured by colorimetric methods and have been used for dilution gaugings are magnesium sulphate, sodium nitrite, potassium chloride and sodium chloride. The lowest concentrations of these that can be determined accurately are generally greater than 1 or 2 mg/l. They are therefore not as favourable as sodium dichromate because inconveniently large volumes of injection fluid are required.

Conductivity and resistivity measurements with Wheatstone Bridges and similar instruments have been used for determining concentrations of sodium chloride (common salt) down to about 20 mg/l. Investigations are now proceeding in Great Britain to develop instruments capable of accurately measuring the resistances of much lower concentrations and, if these are successful, sodium chloride could become a very suitable chemical for dilution gaugings<sup>(10)</sup>.

A series of tests of the constant injection method with sodium chloride was carried out by the State Electricity Commission of Victoria between 1956 and 1960. The objective of these tests was to measure the flows through tunnels, aqueducts and several small creeks for the Kiewa Hydro-Electric Scheme. The flows measured varied from about 1 cfs up to 370 cfs with most values less than 40 cfs. A 600 gallon capacity header tank was used with the injection apparatus and the sample concentrations were determined by both chemical titration and electrical conductivity with close agreement (to 1%) between the two<sup>(22)</sup>.

In these tests a number of independent check measurements by V notch weir and stream gauging differed

from the dilution gaugings by only 2 or 3%, showing that good results may be obtained with sodium chloride if the large quantities of salt and bulky injection apparatus can be tolerated.

Flame photometry is often used for measuring small concentrations of chemicals such as sodium, potassium, calcium and lithium and this principle has been tried for dilution gaugings by Simpson<sup>(11)</sup> and Allenby<sup>(12)</sup>. Simpson suggests that concentrations of potassium and calcium may be measured as low as 5 mg/l while Allenby quotes concentrations of 0.5 mg/l for lithium.

Radioactive and fluorescent materials may be measured accurately at much lower concentrations than sodium dichromate, and for this reason some authorities consider that these materials have the greatest potential of all for streamflow measurement. The application of radioactive isotopes to streamflow measurement is described thoroughly elsewhere and is beyond the scope of this report.<sup>(13),(14),(15)</sup>

In the application of fluorescent materials it is necessary to analyse the stream samples with a laboratory fluorometer, which is a somewhat similar procedure to colorimetric analysis. The United States Geological Survey<sup>(7)</sup>,<sup>(16)</sup> has recently issued a manual describing the practical aspects in detail and indicating the precautions necessary for reasonable results. The suggested chemicals are rhodamine B, pontacyl pink and rhodamine WT, the last of these three being the most favoured. Evidently the method is generally satisfactory although serious errors sometimes occur due to the fluorescent material being adsorbed by certain types of clay and organic matter<sup>(17)</sup>.

Perhaps the most unusual materials suggested for chemical gauging are micro-organisms such as protozoa and bacteria. A. James<sup>(18)</sup> carried out several gaugings with *Serratia indica* which were readily counted under a microscope and were clearly distinguished from other organisms. After the injection of a dense culture the diluted colonies in the stream samples were allowed to multiply under controlled conditions for 48 hours. This permitted an accurate determination of the degree of dilution with the resulting estimated flows agreeing quite well with the known flows.

### 3. INVESTIGATION OF METHOD USING LABORATORY FLUME

#### 3.1 Objectives and Procedure

It was considered desirable for the initial tests to be carried out in a flume at the Water Research Laboratory of the University of New South Wales, Manly Vale, so that a very accurate check could be kept on the actual flows being measured. The general objectives were to permit the investigators to become thoroughly familiar with the method and to assess its reliability under ideal conditions.

After the construction, assembly and calibration of the apparatus, many trial gaugings were made in the flume with sodium dichromate solution over a period of several months and their results were compared with the known flows which varied from 0.29 to 3.72 cfs. In all cases the constant injection method was adopted as this is usually regarded as more reliable than the sudden injection method.



Investigations were made of the mixing conditions in the flume, the times required for steady concentrations to be attained, and the effects of different strengths of injection solution. The effects of time delays between sampling and analysis and different types of water were also examined.

### 3.2 Description of Apparatus

The constant rate injection apparatus shown in Figs. 2 and 3 and described in 2.4 was constructed in the University Workshop from plans kindly supplied by the Office Federal de l'Economie Hydraulique, Switzerland. The capacity of the header tank is 40 gallons and the constant-head vessel has five alternative injection orifices with diameters of 3, 4, 6, 8 and 10 mm. These orifices were calibrated with water rather than dichromate solution as studies by Andre have shown that the errors due to this are unlikely to exceed 1%.

The flume was tilted at a slope of 1% with dimensions 120 ft. long by 24 ins. wide and 22 ins. deep. A pipe and valve arrangement with baffles allowed a range of steady flows up to about 4 cfs. Just downstream of the injection point several housebricks were placed in the flume to increase the turbulence and so improve the mixing conditions. The outflow from the flume could be diverted into a large concrete volumetric tank which enabled accurate calculations of the steady flows to be made.

The sampling of water from the flume was carried out by means of a small, battery-driven centrifugal pump connected to a withdrawal tube which could be clamped in any position in the selected cross section of the flume.

The withdrawn water was delivered directly to the sampling bottles as required.

Half-pint milk bottles were found to be suitable for sampling bottles. About four dozen of these were numbered and fitted with rubber stoppers which were also numbered. A plywood case with special compartments for holding the bottles was used for transporting the samples and keeping them out of the light. (See Fig.2).

The facilities of the Department of Water Engineering Public Health Engineering Laboratory were used for the chemical analyses. The facilities included a Bausch and Lomb Spectronic 20 Colorimeter which gave direct readings of the percentages of light transmitted through the samples after their treatment with diphenylcarbazine reagent as described in 2.5. This instrument enabled concentrations of sodium dichromate to be determined within .01 mg/l with a lower limit of .20 mg/l and an upper limit of 5.00 mg/l.

### 3.3 Results of Tests in Flume

The results of the separate flow measurements made in the flume are summarized in Table 1 which also shows the corresponding check measurements by volume determination. In general, the agreement between the two measurements is satisfactory, the mean of the percentage differences being -0.2%. This means that the chemical gaugings give slightly lower values than the volume determinations. The standard deviation of the percentage differences is 4.5% which may be regarded as a measure of the accuracy of the method under the conditions at Manly Vale.

The mixing conditions in the flume were found satisfactory for any sampling section more than 40 feet downstream of the injection site. No differences in this respect could be detected due to differences in injection rate, injection fluid concentration or flow in the flume, but some variability due to these factors probably would have been found if additional samples had been taken nearer to the injection point. The main sampling site was established 80' downstream of the injection point.

The time delay between the commencement of injection and the attainment of steady concentrations at the main sampling site varied from about 10 to 15 minutes. All of the gaugings in Table 1 were made with a minimum delay of 20 minutes.

The "ageing" of the samples due to reduction of the dichromate, as mentioned in 2.5, was found to be insignificant if the chemical analysis was carried out within 3 days of the gauging and the samples were kept in darkness. Delays of 1 week, however, resulted in apparent losses of concentration of about 5% while delays of 3 weeks (even with the samples in darkness) resulted in apparent losses of from 10% to 15%.

#### 4. INVESTIGATION OF METHOD FOR NATURAL STREAMS

##### 4.1 Objectives and Procedure

The previously described flume tests showed that chemical gauging could give satisfactory flow measurements under ideal conditions with flows less than 4 cfs. The next step was to test the method under a wide range of typical field conditions and with a greater range of flows.

TABLE I

Chemical Gaugings in Flume						
Date	Depth of Flow ft.	Mean Vel. ft/sec.	(a) Discharge by Chem. Gaug. cfs	(b) Discharge by Vol. measure- ment cfs	Difference (a) - (b) cfs	% Difference (a) - (b)
12.5.67	Not observed		3.02	3.11	- .09	- 3
15.5.67	"	"	3.62	3.31	+ .31	+ 9
26.5.67	"	"	1.95	1.89	+ .06	+ 3
7.6.67	"	"	2.62	2.84	- .22	- 8
"	"	"	3.68	3.72	- .04	- 1
14.6.67	"	"	3.32	3.38	- .06	- 2
21.6.67	"	"	3.22	2.99	+ .23	+ 7
"	"	"	3.21	2.97	+ .24	+ 8
23.6.67	"	"	3.13	3.14	- .01	0
12.12.67	"	"	3.11	2.90	+ .21	+ 7
17.1.68	0.87	1.13	1.91	1.97	- .06	- 3
"	1.11	1.41	3.37	3.10	+ .27	+ 9
"	0.69	0.78	1.14	1.07	+ .07	+ 7
15.2.68	1.08	1.39	2.90	3.00	- .10	- 3
"	1.00	1.32	2.42	2.64	- .22	- 8
"	0.90	1.12	1.96	2.02	- .06	- 3
"	0.82	1.03	1.74	1.69	- .05	- 3
21.2.68	0.90	1.32	2.16	2.38	- .22	- 9
22.2.68	0.77	1.52	2.30	2.33	- .03	- 1
"	0.77	1.52	2.39	2.33	+ .06	+ 3
"	0.53	1.21	1.31	1.28	+ .03	+ 2
"	0.53	1.21	1.35	1.28	+ .07	+ 5
29.2.68	1.22	1.37	3.35	3.34	+ .01	0
"	0.54	1.22	1.30	1.32	- .02	- 2
18.3.68	0.87	1.29	2.32	2.24	+ 0.08	+ 4
"	0.45	1.19	1.05	1.07	- 0.02	- 2
"	0.35	0.90	0.63	0.63	0.0	0
"	Not observed		0.29	0.29	0.0	0
"	0.70	1.31	1.78	1.83	- 0.05	- 3
"	0.78	1.28	2.01	2.00	+ 0.01	+ 0
"	1.05	1.34	2.71	2.82	- 0.11	- 4
"	1.27	1.41	3.32	3.59	- 0.27	- 8

Mean of % differences = -0.2%

Standard deviation of % differences = 4.5%

≈ probable error

It was apparent from the flume tests that the injection apparatus of Figs. 2 and 3 would be cumbersome and inconvenient in many field situations, so various modifications and other types of injection devices were investigated. It was also considered desirable to examine briefly the sudden injection method of chemical gauging.

The streams selected for the tests were mainly in the Blue Mountains and Hacking River areas near Sydney and included several of the experimental catchments of the University of New South Wales. It was convenient, also, to carry out a series of tests in a small creek next to the Water Research Laboratory at Manly Vale where controlled flows of up to 5 cfs could be obtained. A further series of tests were carried out in the Snowy Mountains area in co-operation with the Snowy Mountains Hydro-Electric Authority.

#### 4.2 Description of Creek at Manly Vale

This creek has a gently sloping channel 3 feet to 6 feet wide, 1 foot to 2 feet deep and velocities of 1.0 to 1.5 ft/sec at a flow of 5 cfs. A sharp-edged, rectangular measuring weir 4.50 feet wide was installed in the creek in a position where the nappe had an uninterrupted fall of about 2 feet. Controlled flows were released into the creek from the Water Research Laboratory at a point 220 feet upstream of the weir.

The mixing conditions were relatively good, the injection site being 70 feet upstream of the weir and the sampling site 10 feet downstream of the weir.

#### 4.3 Description of Hacking River Sites

The selected sites were the Hacking River at

Upper Causeway, Hacking River at Ferndale, Hacking River downstream of Wilson's Creek, Hacking River downstream of Cawley's Creek, Boora Creek at the Culvert and Cawley's Creek at Lower Cawley's gauging station. In all of these streams the mixing conditions were fair at low flows when the streams consisted of alternating shallow pools and rapids. At high flows the mixing conditions were fair to good with fast, turbulent flows and little deadwater.

Check gaugings at all sites were made by current meter.

#### 4.4 Description of Blue Mountains Sites

The selected sites were the Nepean River downstream of Yarramundi Bridge, Hawkesbury River downstream of Grose River and the Grose River near Cableway gauging station. The measurements in these streams were made only during low flows when mixing conditions were poor and distances of the order of 1400 to 2400 feet were required between the injection points and sampling sections. The Nepean and Hawkesbury Rivers consisted of broad, shallow pools 50 to 100 feet wide with velocities rarely exceeding 0.5 ft/sec. Faster velocities, averaging about 1 ft/sec, prevailed in the Gross River but there was little turbulence in this stream as the flows were relatively uniform in a straight channel about 60 feet wide. Check gaugings at all of these sites were made by current meter.

One chemical gauging and two current meter check gaugings were made during a flood in South Creek at Mulgoa Road. The injection fluid was discharged into the nappe over a weir, downstream of which the flow was fairly turbulent and confined within a channel 12 feet wide by

5 feet deep. Samples were taken about 100 feet downstream of the weir.

#### 4.5 Description of Snowy Mountains Sites

The selected sites were Bogong Creek near Geehi Road, Snowy Creek near Tom Groggin and the Murray River at Tom Groggin. Bogong Creek and Snowy Creek were turbulent mountain streams with good mixing conditions. The Murray River was a much larger stream with fair mixing conditions, having sections of rapids alternating with deep pools. The check gaugings for these three streams were made by current meter by officers of the Snowy Mountains Authority.

A chemical gauging in this area was also made in Bourke's Gorge Aqueduct where the flow passed through a triangular weir and two stilling wells. An established rating table was available for checking this measurement.

#### 4.6 Attempts to Improve Injection Procedure

The constant-head injection apparatus used in the flume tests was difficult to assemble in suitable injection positions on natural streams. This was due to:

- (a) the pieces of equipment being awkward and heavy to carry,
- (b) the difficulty of raising the 40-gallon header tank to a sufficient height for proper functioning,
- (c) the fast-flowing sections of the stream generally being some distance from the bank.

Some improvements in these matters resulted from the design and construction of a lightweight supporting frame and a long trough. However, for flows less than 100 cfs it was found more convenient to use one or two mariotte vessels as described in 2.4, rather than the constant-head apparatus of the flume tests.

Two 5-gallon and one 10-gallon mariotte vessel were tested under a wide range of field conditions. The injection rates from these vessels were found to vary by less than 3% during any particular gauging, provided that care had been taken to ensure the cleanliness of the equipment. It was necessary to pour the injection solution into the vessel through a funnel and filter to prevent the entry of undissolved particles and foreign matter that could lodge in the nozzle. With this precaution, together with a thorough rinsing of the nozzles and other parts after each gauging, the mariotte vessels performed very satisfactorily.

Several other types of injection apparatus were examined but none of these were as convenient to use as the mariotte vessels. A floating siphon device was constructed along the lines suggested by the British Standards Institution<sup>(2)</sup> but this was found to give more variable injection rates than the mariotte vessels and was subject to other malfunctions. None of the commercially available control valves with differential regulators could be used effectively with the low pressures of the injection fluid. Battery-driven pumps may be quite suitable for providing a constant injection rate but the only ones that were readily available for the project did not appear to have any advantages over the mariotte vessels.



Although the sudden injection method avoids the problems of injection devices, the initial field trials of this method indicated that it required a larger number of stream samples than the constant rate method. Because of this disadvantage and other doubts about its reliability the method was not tested extensively.

#### 4.7 Results of Field Tests

The results of the field tests are shown in Table 2. The mean of the % differences is -1.7% which indicates that the chemical gaugings tended to give slightly lower discharges than the check gaugings by current meter.

If it is assumed that the probable error in a check gauging by current meter is 5% (which may be somewhat optimistic) it may be shown that the probable error of any single chemical gauging in Table 2 is approximately 6%. This may be calculated from the standard deviation of the % differences which is 8.0%. The accuracy of chemical gaugings is therefore about the same as for current meter gaugings.

Five of the gaugings in Table 2 have been deleted. In each case there is reasonable evidence to show that gross errors have occurred due to one or more of the following:

- (a) incomplete mixing at the sampling site as shown by the laboratory analyses of the samples,
- (b) completion of sampling before the attainment of steady concentrations,

- (c) stream sample concentrations too weak to be measured accurately.

Some of the above gross errors were detected in the field in gaugings which were immediately abandoned. Other gaugings were abandoned in the field before completion because volumetric checks on the injection rates showed that they were not constant, generally due to foreign matter caught in the nozzle. The flows for these gaugings were not calculated and their particulars are not listed in Table 2.

The adoption of the mariotte vessels in preference to the larger constant-head apparatus did not reduce the accuracy of the measurements. However the capacities of the mariotte vessels were inadequate for flows exceeding 100 cfs, e.g. those of the Murray River at Tom Groggin.

Although most of the chemical gaugings in Table 2 were quite satisfactory, these results were not obtained easily. It was found that successful applications of the method required careful attention to a number of details that are readily overlooked. Most of these details will be dealt with below.

## 5. DETAILS OF METHOD REQUIRING SPECIAL ATTENTION

### 5.1 Estimation of Mixing Length

The estimation of mixing length provided no problems in the laboratory flume tests but in the field tests it was a major source of difficulties. When the mixing length was underestimated the calculated stream-flows were either too large or too small, depending on whether the stream samples were taken in the slower or faster parts of the flow. On the other hand, when the

TABLE 2  
RESULTS OF FIELD TESTS

Location of Gaugings	Date	Injection Apparatus	Discharge by Chemical Gauging	Discharge by Current Meter	% Difference
			cfs	cfs	
Creek at Manly Vale	27.1.68	G	5.04	5.03 <sup>a</sup>	+ 0
" " " "	"	G	5.40	5.03 <sup>a</sup>	+ 7
" " " "	"	G	5.12	5.03 <sup>a</sup>	+ 2
" " " "	"	G	4.86	5.03 <sup>a</sup>	- 3
" " " "	10.2.68	G	1.50	1.61 <sup>a</sup>	- 7
" " " "	"	G	2.02	2.00 <sup>a</sup>	+ 1
" " " "	"	G	2.12	2.00 <sup>a</sup>	+ 6
" " " "	"	G	4.17	3.80 <sup>a</sup>	+ 10
" " " "	29.2.68	G	4.37	4.20 <sup>a</sup>	+ 4
" " " "	"	G	4.37	4.20 <sup>a</sup>	+ 4
" " " "	"	G	4.28	4.20 <sup>a</sup>	+ 2
" " " "	8.3.68	G	4.30	4.20 <sup>a</sup>	+ 2
" " " "	"	G	4.34	4.20 <sup>a</sup>	+ 3
" " " "	"	G	4.40	4.20 <sup>a</sup>	+ 5
Hacking R. at Upper Causeway	5.4.68	G	0.73	0.75	- 3
" " " "	"	G	0.64	0.75	- 15
" " " "	"	-	0.63 <sup>b</sup>	0.75	- 15
" " " "	"	-	0.61 <sup>b</sup>	0.75	- 19
Nepean R. at Yarramundi	24.4.68	G	6.30	18.2	deleted
" " " "	"	-	12.4 <sup>b</sup>	18.5	deleted
" " " "	3.6.68	G	29.1	{ 26.6 27.7	+ 7
" " " "	"	G	27.7		+ 2
" " " "	"	G	26.4		- 2
" " " "	13.6.68	G	20.4	21.6	- 6
" " " "	"	G	21.5	21.6	0
" " " "	"	G	21.0	21.6	- 4
" " " "	"	G	23.4	21.6	+ 8
Grose R. near Cableway	2.7.68	M	29.0	34.5	- 16
Hacking R. at Upper Causeway	4.7.68	M	0.86	0.92	- 6
" " " "	25.7.68	M	2.02	2.08	- 3
Hacking R. D/s Wilson's Ck.	"	M	1.40	1.24	+ 13
Hacking R. D/s Cawley's Ck.	"	M	4.97	2.08	deleted
Cawley's Ck. at Lower Cawley's	"	M	0.50	0.70 <sup>c</sup>	deleted
Nepean R. at Yarramundi	1.8.68	M	22.7	26.4	- 14
Hacking R. at Upper Causeway	20.8.68	M	0.98	0.88 <sup>c</sup>	+ 11
Cawley's Ck. at Lower Cawley's	"	M	0.37	0.40 <sup>c</sup>	- 7
Grose R. near Yarramundi	22.8.68	M	27.2	28.5	- 5
Hawkesbury R. D/s Grose Jtn.	"	M	32.3	40.1 <sup>d</sup>	- 19
Nepean R. at Yarramundi	20.9.68	M	8.75	8.60	+ 1
" " " "	"	-	8.72 <sup>b</sup>	8.60	+ 1

TABLE 2 (Cont'd.)

Location of Gaugings	Date	Injection Apparatus	Discharge by Chemical Gauging	Discharge by Current Meter	% Difference
Snowy Ck. near Tom Groggin	3.12.68	M	9.30	9.58	- 3
Murray R. at Tom Groggin	"	G	287	212	deleted
Bogong Ck. near Geehi Road	4.12.68	M	41.4	45.9	- 10
Bourke's Gorge Aquaduct	"	M	56.1	54.9	+ 2
Bogong Ck. near Geehi Road	5.12.68	M	43.2	45.4	- 5
" " " "	"	-	41.2 <sup>b</sup>	45.4	- 9
Murray R. at Tom Groggin	"	G	246	210	+ 17
Boora Creek at Culvert	11. 2.69	M	2.34	2.44	- 4
Hacking R. at Ferndale	"	M	78.0	75.3	+ 4
South Ck. at Mulgoa Rd.	12. 2.69	M	42.5	{ 46.9 44.1	- 7
Hacking R. at Upper Causeway	13. 2.69	M	19.9	22.5	- 12

Mean of % differences = -1.7%

Standard deviation of % differences = 8.0%

Calculated Probable Error, assuming  
probable error of 5.0% in check  
gaugings = 6.0%

#### NOTES

- a Check discharge by measuring weir.
- b Sudden injection gauging.
- c Check discharge from rating table.
- d Check discharge estimated by adding flows of Nepean and Grose Rivers.
- G 40-gallon constant-head injection apparatus.
- M Mariotte vessels.

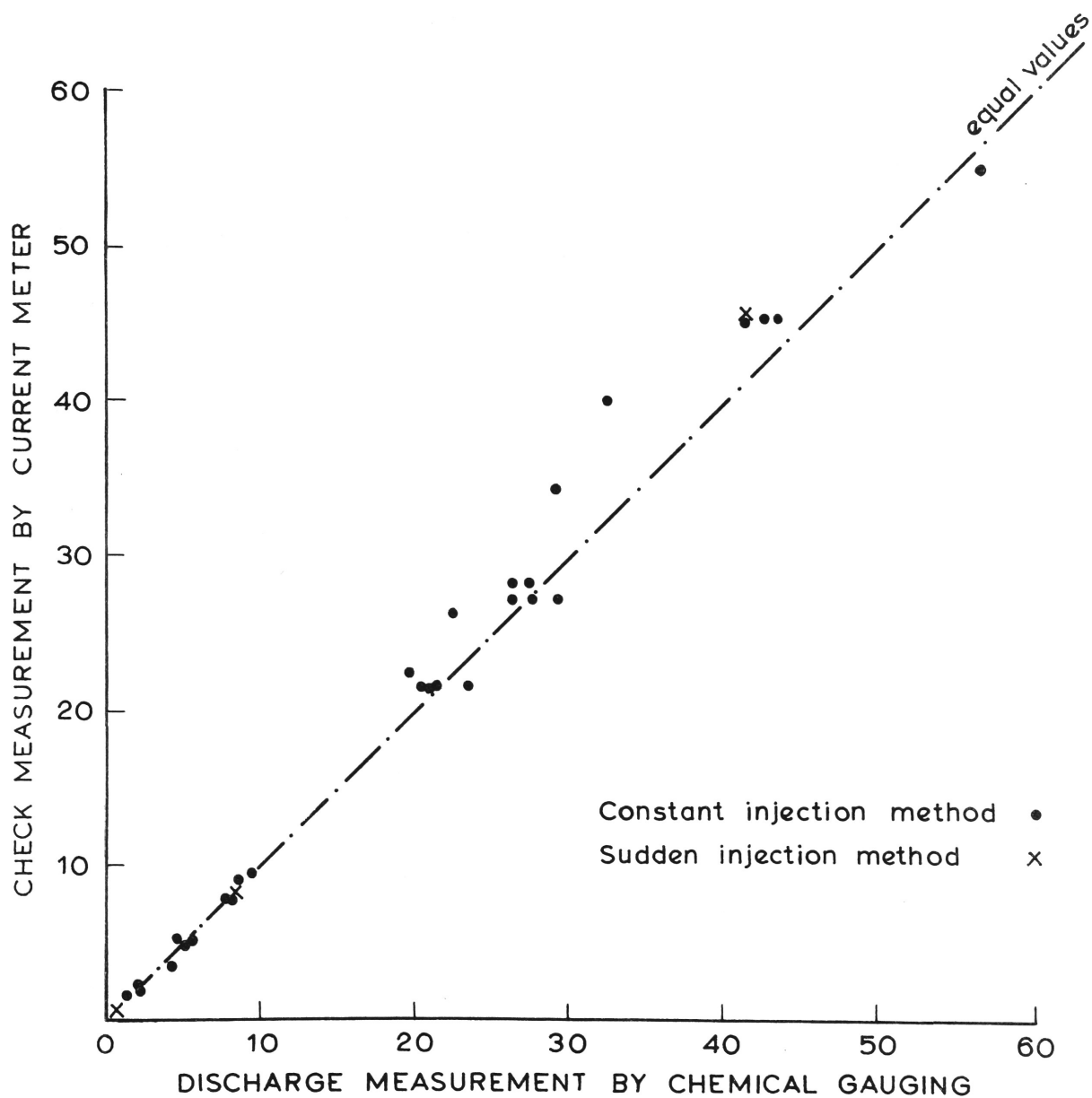


FIG.5: COMPARISON BETWEEN CHEMICAL GAUGINGS  
AND CHECK MEASUREMENTS

mixing length was overestimated, excessively large amounts of injection fluid and excessively long injection durations were required, sometimes to such an extent that the method became impractical with the available apparatus.

The most reliable way of estimating the mixing length was to collect several samples from selected cross sections and immediately treat these with diphenylcarbazide reagent at the site. Visual inspection of the intensities of reaction was found adequate to detect non-uniformity of mixing in any particular cross section. Unfortunately this was a very time-consuming procedure and would probably not be very practical for routine measurements of streamflow.

Observations of fluorescein dye dispersion tended to result in underestimates of the mixing length, particularly for the broad, shallow streams of the Blue Mountains area in which it was difficult to judge the uniformity of colouring across the stream section. When 20% was added to the estimates by this method they agreed very well with the estimates obtained by sampling and treating with reagent.

Table 3 shows how the mixing lengths estimated by the above methods compared with those calculated by the formulae described earlier in 2.3. A very wide range of values is given by the different methods and it appears that none of the available formulae are very satisfactory for the streams investigated. These results are similar to the findings of other studies of mixing length by Spencer and Laird<sup>(9)</sup> and Barsby<sup>(4)</sup>.

The deficiencies in Hull's and Andre's formulae are not surprising as neither takes into account the roughness or irregularity of the flow conditions which is

TABLE 3  
ESTIMATION OF MIXING LENGTH

Stream	Flow	Width	Depth	Roughness	No. of	Lateral	Estimated Mixing Length			
	Q	W	D	C	Injection	Dispersion	By	By	By	By Dye
	cfs	ft.	ft.	fps units	Points	Distance	Rimmar's Formula	Hull's Formula	Andre's Formula	Dispersion or Sampling
						B ft.	ft.	ft.	ft.	ft.
Creek at Manly Vale	5.03	5	1.2	50	1	2.5	210	31	230	70
	2.00	5	1.0	50	1	2.5	250	34	170	70
Nepean River	27.7	50	1.5	60	1	25	22100	860	3700	1400
at	26.4	50	1.5	60	1	25	22100	860	3700	1400
Yarramundi	26.4	50	1.5	60	2	17	22100	860	3700	1000
Grose R. at Cableway	28.5	60	1.0	75	1	30	74000	1400	5000	2300
Hacking R. at U/Cause- way	0.92	12	0.8	40	1	6	1060	140	324	100
Hacking R. D/s Wilson's Ck.	1.40	9	1.0	60	1	4.5	1080	81	268	280
Cawley's Ck. at Lower Cawleys	0.40	4	0.5	40	1	2	200	34	80	70
Hacking R. at Ferndale	75.3	32	2.5	40	2	12	2420	343	360	280

undoubtedly one of the main factors. The estimates by Rimmar's formula depend largely on the Chezy coefficient of roughness which is not necessarily a good index of the lateral mixing conditions in the stream, particularly in the case of broad, shallow streams. It seems that if a more reliable formula is to be developed, special attention should be given to the quantitative expression of the lateral mixing efficiency of the flow, which may be quite difficult.

In the streams gauged in this investigation it was found that a rough, but simple guide to the mixing length was given by:

$$\begin{aligned}\frac{L}{B} &= 20 \text{ to } 40 \text{ for good lateral mixing i.e. with} \\ &\quad \text{bends, rapids and little deadwater,} \\ &= 40 \text{ to } 60 \text{ for fair lateral mixing,} \\ &= 60 \text{ to } 100 \text{ or more for poor lateral mixing.}\end{aligned}$$

In the above,  $L$  is the mixing length and  $B$  is the estimated lateral dispersion distance which depends on the width of the stream  $W$ , the number of injection points and the position of the injection points. For a single injection point in the centre of the stream  $B = \frac{W}{2}$  while for a single injection point near the bank  $B = W$ . For  $n$  injection points equally spaced across the stream  $B = \frac{W}{n+1}$ .

The above rough guide is not recommended as a substitute for the estimation of mixing length by observation of dye dispersion but it may prove useful for assessing the feasibility of chemical gaugings in various circumstances.



## 5.2 Estimation of Injection or Sampling Duration

The most reliable way of estimating the minimum injection duration was to examine at suitable intervals the reactions of some of the samples with diphenylcarbazine at the site, in a similar manner to the estimation of mixing length. In fact it was found desirable to do both of these jobs simultaneously, otherwise it was uncertain whether non-uniformity in a particular section was due to incomplete lateral mixing or to insufficient time for the development of steady concentrations in the mixing reach. A further check on the steadiness of the concentrations was usually provided, however, by the laboratory analyses of stream samples taken at different times.

Fluorescein dye dispersion proved to be a satisfactory indicator of the required injection duration. If a "slug" of dye was released at the commencement of the injection it was found that steady concentrations had usually developed after the passage of the dye through the mixing length when most of the visible traces had disappeared at the sampling section. The dye had no effect on the colorimetric analysis, as explained later in 5.8.

An approximate guide to the required injection duration was given by:

$$T = \frac{L}{30V}$$

where  $T$  = minimum duration in minutes,  
 $L$  = adopted mixing length in feet,  
 $V$  = estimated mean velocity in  
mixing reach in ft/sec.

The above formula was found to give satisfactory estimates for the field conditions of this investigation in which the mean velocities varied from about 0.3 ft/sec to 3.0 ft/sec, but it may not be suitable for other conditions.

### 5.3 Requirements of Injection Solution

Several early gaugings failed because the injection solutions were too weak and the final stream concentrations were consequently too low for accurate colorimetric analyses. These failures were later avoided by allowing a minimum of 1.5 gm of sodium dichromate per minute of injection time per cfs of streamflow. Thus, for an injection duration of 20 minutes and a flow of approximately 10 cfs it would be necessary to release at least  $1.5 \times 20 \times 10 = 300$  gm of dichromate.

It was found very advantageous to accurately weigh and mix the injection solution before each gauging. In many cases, however, this was difficult to do under field conditions and it was therefore necessary to take samples of the injection fluid for later laboratory determinations of its concentration. These laboratory determinations required considerable care and patience as the injection fluid had to be diluted accurately by very large amounts (up to 100,000 times) before useful colorimeter readings were possible.

To avoid undissolved particles and uneven mixing in the injection apparatus the following precautions were adopted:

- (a) the injection solution was thoroughly mixed in a bucket before being poured into the mariotte or constant-head vessels,

- (b) the concentration of the solution was not allowed to exceed 400 gm/l,
- (c) the solution was poured through a funnel and filter into the injection vessels.

When the 40-gallon header tank was used, the solution in the tank was stirred with a large, perforated paddle for several minutes. The solution was also circulated through the constant-head vessel and returned to the header tank for about 10 minutes before the commencement of the injection to ensure a thorough rinsing of the apparatus.

#### 5.4 Measurement of Injection Rate

Although the mariotte vessels and constant-head vessel had been calibrated in the laboratory it was found necessary to check the injection rate at the start and end of each chemical gauging. This was done with a stopwatch and measuring cylinder, the time being noted for the injection of a selected volume of solution.

Although the rate of injection usually did not vary more than 1% or 2% during any particular gauging there were often variations of 5% or more between different gaugings. These variations between gaugings were probably caused by temperature effects, slightly different positions of the air inlet pipe and similar minor factors.

#### 5.5 "Ageing" of Stream Samples

The gradual chemical reduction of sodium dichromate due to organic agents in the water, especially in the presence of light, was mentioned in 2.5 and 3.3.

This affect would vary considerably with different types of water and it could probably be quite important under some circumstances. In most of the field tests the samples were kept in darkness and analysed as soon as possible after collection. A delay of 24 hours did not seem to have any adverse effects on the gaugings but longer delays than this are not recommended.

#### 5.6 Stability of Reagent

In order to convert the colorimeter readings to concentrations of dichromate a calibration curve had to be prepared for each batch of diphenylcarbazine reagent. This curve was plotted graphically from the colorimeter readings of a number of accurately measured solutions that were made up in the laboratory. The diphenylcarbazine reagent was prepared in 400 ml batches as outlined in the manual of the American Public Health Association<sup>(8)</sup>. Unfortunately each batch seemed to have a different calibration curve as shown by the typical examples in Fig. 6.

It was essential to keep the reagent under refrigeration to ensure that its calibration remained valid for a reasonable period (about 4 weeks). Without refrigeration the reagent became unstable after a few days and its original calibration no longer applied.

#### 5.7 Colorimetric Analysis

The reaction of diphenylcarbazine with sodium dichromate was described in 2.5. It was found that serious errors occurred if the colorimetric analysis was carried

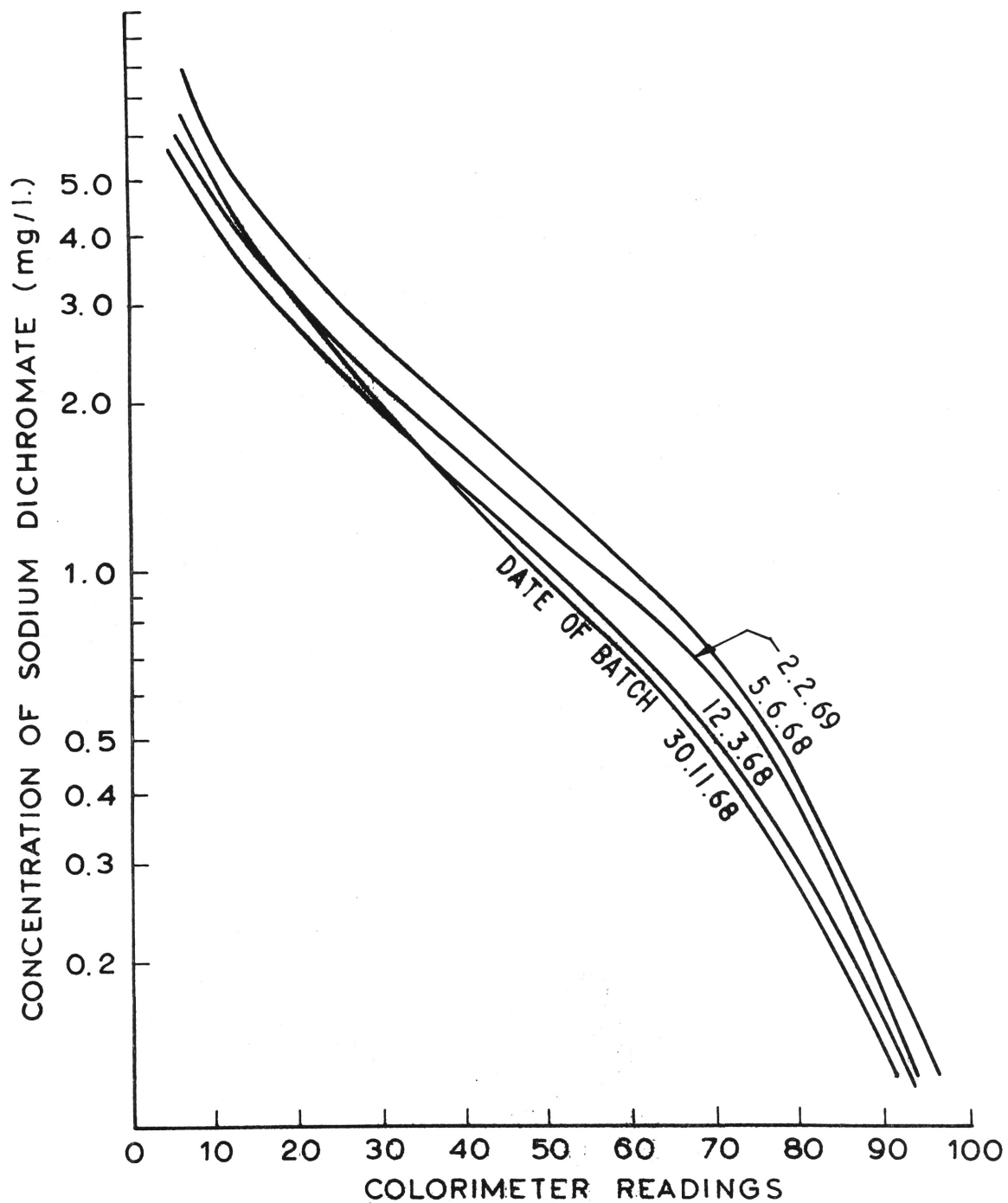


FIG. 6. TYPICAL REAGENT CALIBRATION CURVES.

out too soon or too long after the reaction. In general, the colour remained at its maximum intensity between 10 minutes and 25 minutes after the reaction but in a few cases the maximum intensity was reached after only 5 minutes and it commenced to fade 15 minutes after the reaction. In these cases the stream samples tended to have relatively high concentrations (3.0 to 6.0 mg/l) and it is considered that this may account for the difference in the reaction.

Even when careful attention was given to the time of the colorimeter reading after the reaction, differences of 5% or more between individual readings of the same sample were not uncommon. Good results were obtained when each sample was divided into three batches with three separate reactions. Three colorimeter readings of each batch were then made, making a total of nine readings for every sample. The mean value of the nine readings was adopted for the calculation of the concentration. This procedure did not increase the time of the laboratory work by a large amount and proved to be well justified.

Another source of error was found to be in the adjustment of the colorimeter scale. It was necessary to adjust the scale at both upper and lower ends at frequent intervals during a set of readings because a gradual change occurred as the instrument changed temperature. This was found necessary even after a "warming-up" period of about 30 minutes. The lower end of the scale was adjusted by setting it on zero with the tube aperture closed. The upper end was adjusted by setting it on 100% with a sample of the stream water that had been collected before the commencement of injection.

### 5.8 Effects of Turbidity and Fluorescein on Colorimetric Analyses

It seemed that the use of fluorescein for the estimation of mixing lengths could have detrimental effects on the colorimetric analyses of the stream samples because traces of green fluorescein colouring were often present in the samples. Several series of colorimetric analyses were made, therefore, with different solutions of dichromate and fluorescein in various combinations to determine the magnitudes of any such effects.

For the wavelength of 540  $m\mu$  normally used for dichromate analysis no variations in colorimeter readings could be attributed to the fluorescein except when the colouring was so strong that a reddish tinge appeared. As this condition is unlikely to occur in an actual gauging it may be concluded that fluorescein does not affect the colorimetric analyses.

Different results were obtained with a series of similar tests on turbid water taken from South Creek during a flood. This water contained a considerable amount of suspended brown clay which seriously altered the colorimeter readings. It was necessary to remove the turbidity by filtration before accurate determinations of the dichromate concentration could be made.

A significant but smaller effect on the colorimeter readings was detected, in another series of tests on turbid water from the Hacking River. In this case the turbidity was due mainly to ash and charcoal from parts of the catchment affected by bushfires. Turbidity is therefore another source of error in chemical gauging and efforts must be made to minimise its effects if accurate flow measurements

are to be made.

### 5.9 Toxicity of Sodium Dichromate

In the field tests the final concentrations of sodium dichromate in the water were usually less than 1 or 2 mg/l and these concentrations rapidly decreased after the conclusion of the gaugings. It seems that such gaugings are not likely to be detrimental to water supplies or aquatic life under most circumstances, but the possible dangers of the concentrated solutions to gauging personnel should be considered. Various forms of sodium dichromate have been used extensively in the textile dyeing, chromium plating, tanning and lithographic industries, and numerous studies of its toxicity are available in medical, chemical and biological literature.

Occasional direct contact with the skin has caused a number of cases of ulceration and dermatitis while frequent exposure with consequent absorption into the body has been associated with nephritis and cancer. Concentrations of 30 mg/l have been found lethal to fish and plankton, but rats have tolerated up to 25 mg/l in their drinking water for twelve months without detriment.<sup>(19),(20),(21),(9)</sup>

It is advisable to exercise caution in handling dichromate, especially under field conditions when it is often difficult to avoid contact. Light, rubber gloves are probably a necessary item of equipment, although it was found that these sometimes made the situation worse by reducing manual dexterity and preventing the immediate recognition of contact with the skin when it occurred.



A similar problem was the damage to clothing that resulted from contact with dichromate during the field tests. This damage consisted of dark yellow stains which apparently cannot be removed by dry cleaning or any other means.

These difficulties could probably be avoided if gauging personnel are properly advised and suitable precautions are taken, but the necessity to take such precautions tends to reduce the convenience of the method.

## 6. CONCLUSIONS

### 6.1 Accuracy of Chemical Gauging

In this investigation, the constant rate method of chemical gauging gave streamflow measurements with an estimated probable error of 6% in a range of typical Australian conditions. The method therefore has about the same accuracy in turbulent stream sections as current meter measurements have under ordinary flow conditions. This accuracy of the chemical gaugings could possibly be improved with further modifications of the equipment and with the gaining of greater experience by the operators.

For the gauging of flows less than 100 cfs, it was found that simple 5-gallon and 10-gallon mariotte vessels were more convenient to use than the 40-gallon constant-head apparatus. No loss of accuracy resulted from the adoption of the mariotte vessels.

### 6.2 Special Problems of Chemical Gauging

Satisfactory measurements of streamflow by chemical

gauging require careful attention to a number of practical details that may not be fully appreciated under field conditions.

A major source of error is the failure to allow a sufficient mixing length or a sufficient injection duration for steady, uniform concentrations to develop throughout the sampling section. It is recommended that the mixing length and injection duration be estimated from observations of fluorescein dye dispersion, with an addition of 20% as a safety factor. The theoretical formulae available for the estimation of mixing length were found to be unreliable for Australian conditions.

Other details of the method that require close attention are the strength and thorough mixing of the injection solution, the checking of the constancy of the injection rate, the delay between collection and analysis of samples, the delay between the diphenylcarbazide reaction and the colorimeter reading, and the freshness of the reagent.

Finally, it is important to pay scrupulous attention to the cleanliness of all equipment to avoid contamination of the samples and to avoid contact of dichromate with personnel and clothing.

### 6.3 Special Advantages of Chemical Gauging

The investigation suggested that the constant rate method of chemical gauging has the following advantages when compared with current meter gaugings:

- (a) it is suitable for small, turbulent streams and certain hydraulic structures where current meters are difficult to use,
- (b) all operations may be made from one side of the stream and it is not necessary to have a bridge, cableway or similar apparatus across the stream,
- (c) chemical gaugings may be satisfactorily made by one man whereas current meter gaugings usually require two men,
- (d) chemical gaugings are suitable for efficiently measuring flows at several stations in the same locality.

With regard to (d) above, an operator may set up several injection vessels and commence gaugings at different stations within a short time, returning to each when sampling is due. In this manner he may complete a series of gaugings with no additional assistance and little more time than it takes for a single gauging.

The equipment used in this investigation would not be suitable for measuring flows greater than about 250 cfs. It is understood, however, that flows of up to 7000 cfs have been measured in France with much larger header tanks<sup>(1)</sup>.

Several trials of the sudden injection method showed that this method could also give satisfactory measurements of streamflow. Unfortunately its advantages seemed to be outweighed by the extra samples and extra laboratory work required.

The study suggested that chemical gauging with sodium dichromate is not usually superior to current meter gauging when reasonable conditions for the latter are available, for example when fairly regular flows may be found at wading, bridge or cableway sections. However, in other circumstances chemical gauging is a useful ancillary method that should give satisfactory results with experienced and careful operators.

### ACKNOWLEDGEMENTS

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