FIELD TESTING OF THE FLOWSTREAM® INTEGRATING CONDUCTIVITY METER FOR RIVER FLOW ESTIMATION USING THE SALT GULP DILUTION METHOD.

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1. Introduction

The salt gulp dilution method for flow estimation has been used for many years as a simple, cheap and robust technique for use in small, turbulent upland streams, and as such it is in wide use in environmental studies. It is best used where the alternatives are either impractical in rough channels, as is the case using a rotating element current meter, or time-consuming, expensive and requiring specialist operators (e.g. electromagnetic current meters, continuous injection dilution gauging and fixed structures). As is often the case with simple methods, the rigorous application of the gulp method, taking account of the various sources of error and uncertainty, can be a demanding and skilful, even tedious, task, but by adopting good practice, with an experienced operator and the right conditions, the accuracy and precision of this technique can be of a high order.

Salt gulp dilution gauging is particularly good for survey work, where a large number of gaugings need to be carried out over a short period of time, either on a single stream or on a number of streams. However, it is generally limited to low and moderate flows because of the inordinate amount of salt required in other circumstances and because the mixing of tracer at high flows may be more inefficient for a given path length as flows become more laminar and less influenced by channel roughness.

Although simple in principle, the method does require careful application, especially to avoid systematic errors. The most cumbersome aspects of the work include: the initial estimation of weight of salt required for a gauging, the measurement and mixing of salt tracer prior to injection into the stream, the manual recording of conductivity readings and the post-processing of the conductivity data to give flow. Operational advantages can be gained if all or some of these processes are streamlined and automated. Dulas Ltd. have used the salt dilution technique to good effect in many parts of the world, and with their own future use in mind developed the *FlowStream* integrating conductivity meter that can measure stream conductivity and calculate flow automatically in the field. The instrument is clearly of general application to a number of areas of study in engineering, hydrological, chemical and biological research and therefore has some commercial potential as an operational field instrument.

Staff at the Institute of Hydrology's Plynlimon catchment experiment have been commissioned to carry out an independent test of the instrument. They are in the position of being able to act at one and the same time as informed laymen and as staff familiar with the requirements of flow gauging techniques. They are also able to provide backup information from the permanent flow measuring structures in the Plynlimon catchments with which to compare the results from the *FlowStream.*

2. Technical details of the instrument

2.1 The *FlowStream* meter is packaged in a sturdy, hard-plastic enclosure with an IP65 rating. This refers to the standard of waterproofing of the container. Though the unit is not designed for complete immersion, it is adequately protected from rainfall and other situations of low water pressure such as splash when in use at the riverside.

2.2 The battery compartment is accessible, though the Posidriv® screws referred to in the manual were slotted screws on the prototype. The correct layout of the batteries is mentioned in the manual, and usefully the +/- terminals are also marked inside the unit.

2.3 One area of concern is the socket used on the prototype for connection of the conductivity probe. Plug location is good and electrical connection seems adequate, but the plastic screw thread is too easy to cross-thread, especially when trying to tighten the locking ring onto the O-ring seal. Distortion of the cap will lead to a poor seal. Some thought should be given to providing a better plug/socket combination, and also to providing a positive location for the bulkhead unit which was inclined to turn under torque*, allowing the gasket to be over-compressed, so compromising the seal and risking the breakage of internal components.

* We have since inspected a later version in which this socket mounting is provided with a keyway to ensure positive location.

2.4 The front of the unit is clearly marked and well laid out with large buttons that are easy to use when wearing gloves. This is important in areas where hand protection is required to guard against the transmission of diseases. Weil's disease (*Leptospirosis*) is a particular problem in Britain, even in the uplands, and the situation in some developing countries may be worse.

2.5 The display and menu system is easy to read and understand once the manual has been read, and allows the user to follow a logical path through the gauging procedure. During the field tests carried out at Plynlimon, a manual record was kept of the conductivity readings displayed in order to assess the shape of the conductivity curve, which is informative in terms of the tracer mixing, and to check on the internal calculations being performed. In slight rain the LCD display is difficult to read and requires constant wiping which is difficult to do when writing down values in rapid succession. However this is only a problem under test conditions, as collection of raw data is not necessary during normal operations.

2.6 The clock is impressively accurate and needed no correction when the unit was delivered from Dulas, nor has it since. In any case the procedure for altering the time is logical, simple and quick to perform.

2.7 The conductivity probe supplied with the meter was not the type that will eventually be marketed. In spite of its being old and needing some repair before use there is clear evidence that it performed satisfactorily during the tests. There is no reason to believe the production model will not also perform well.

3. The operation manual and field methods

The manual gives a comprehensive guide to the field procedures to be followed, and also includes additional information that allows the operator to obtain a firm idea of the principles involved and the consequences of his/her actions at every stage. In the production model it would be useful to have an encapsulated, single sheet version of the manual (maybe just including the main operational information such as menu options and tracer weight selection table) that could be attached inside the lid, as the paper version will not last long in wet conditions.

Taking the manual in sequence there are one or two comments that might need a little expansion or clarification for the enquiring user.

3.1 The unit is described as being suitable for single person operation. While this is certainly true it may be better to add 'when safe to do so' to take account of the potential dangers of working on a river bank, particularly at high flows.

3.2 The instrument is calibrated using a standard calibration solution of precisely 1413μS cm^{-1}. This is the solution provided by most manufacturers, and is presumably related to the molar concentration of KCl. Whatever the reason, it sits usefully approximately mid-way up the conductivity range of the instrument.

3.3 In *Measuring Flow - Before leaving base* (page 7), it may well be worth recommending (as was suggested verbally to us by Dulas) the filling of plastic bags with known 'round' quantities of salt, probably in units of 250g, 500g, or even 1000g for higher flow situations, which can then be bulked in various combinations to suit the quantities given in the table also on page 7. This measurement can be carried out to a high degree of accuracy in the lab, and much more accurately than is possible in the field, especially on uneven ground and in poor weather conditions. There is also less chance of contamination if the manipulation of bags of salt on the river bank can be minimised. This method will also enable the speeding up of the setting for 'weight of salt added' on the instrument, a point that is discussed further in 4.1.

3.4 In the same section a recommendation is given not to perform tests when there is heavy rain or snow on the catchment, without any reasons being given. It is likely that 'heavy rain' is just the sort of conditions that most hydrologists would want to undertake tests. Valid reasons for such restrictions could be:

i. rapid flow change on the rising limb of the hydrograph
ii. the dangers of the probe being hit by debris
iii. the difficulty of ensuring a constant background conductivity during the test

During snow, the problems could be:

i. a potentially rapid rise in flow
ii. the potential variability in background conductivity
iii. safety considerations when working on snow covered river banks

iv. a function of the air and water temperatures under which the unit is expected to operate

Dulas Ltd. have indicated that the restriction given in the manual is simply a hangover from the original testing of the instrument which was carried out to ascertain the stage-discharge rating of natural channels, and in such circumstances the hysteresis inherent in the relationship during rapid flow change could not easily be accommodated. It is felt after using the instrument, however, that for general flow measurement, or for check calibration of structures or channel reaches with no inherent hysteresis problems, such restrictions are unnecessarily harsh. Cold temperatures, not just during snow, do however give some cause for concern, and this is discussed in the context of the test gaugings in section 5.

3.5 In *On site* (page 7), the recommendation given for prescribing the quantity of salt required is to estimate firstly the cross sectional area of flow. In practice, the width estimation is relatively easy, the depth estimation less so. This is especially true where, as in most rough mountain streams, the depth is variable, refraction means that depth is generally underestimated in any case (leading to a systematic underestimation of salt required), and the water may be turbid. Within its limitations, however, the table provided does give the totally unfamiliar user a starting point. It is probably better to stress the importance of the trial run, data from which, if the operator is lucky, can be used as one of the sample tests, but otherwise enables the quantity of tracer to be optimised very closely for subsequent tests. It might be worth mentioning in the manual that the target peak conductivity ($2*C_b$) can be ensured from the trial results from the following calculation:

$$S_t = S_i / ((C_p/C_b)-1)$$

where: S_i is the salt added in the initial test (g)
S_t is the salt to be used in subsequent tests at the same or similar flow (g)
C_p is the peak conductivity for the initial test ($\mu S\ cm^{-1}$)
C_b is the background conductivity ($\mu S\ cm^{-1}$)

3.6 Tests carried out (see section 6) suggest that perfectly good results can be obtained by achieving peak conductivities 200% of background. There seems little point therefore in wasting tracer by exceeding the amount that will achieve this. The table on page 7 is a useful guide to the initial amount of tracer required but should only be seen as a first iteration, not as a substitute for the initial trial. It should be made clear in the table that the conductivity ranges given are for background conductivity. By using the table, in each test carried out (see section 6) the peak conductivity achieved was lower than $2*C_b$, but was always close enough to allow a good estimate of tracer required for subsequent tests.

3.7 In *Performing a test* (pages 8 & 9), there is a recommendation not to choose a reach with stagnant pools (< 0.1 m sec^{-1}). This can be quite difficult to achieve in practice, especially where flow estimation is required at a specific point, for instance: upstream of a flow measuring structure the operator is trying to calibrate, or where inflows exist that may not effect the gauging itself (see page 10 of the manual) but where moving the test reach upstream or downstream will change appreciably the catchment area of the stream being measured. One of the sites chosen for the tests described in section 6, the Upper Hore, had a series of waterfalls where mixing was good and plunge pools where velocities were low. The advantages of good mixing probably outweighed the disadvantages of the extended test period required to regain background conductivity, but in any case there was no better choice of reach at this particular site. The results indicate that the existence of low velocity, high storage areas need not compromise the accuracy of the flow estimate, though they can and do considerably extend the time required for each gauging.

3.8 At both test sites the recommendation of 20 x channel width was used and found to be reasonable for good mixing. However, the only literature reference know to us that uses so simple an expression for the mixing length recommends instead a factor of 25. At one site, the Hafren, it was easy to estimate width, but at the other, the Upper Hore, it was much less so, the width varying by a factor of more than four within this rocky reach. However, such turbulent flow was achieved in the narrow sections that good mixing was assured even if the path length had been underestimated. Where several tests are carried out on the same river reach as part of the same exercise, the repeatability of results will itself be a measure of the quality of mixing obtained, as flows in highly turbulent streams are unstable and non-uniform concentrations in the sampling cross-section will show up as fluctuations in conductivity measured at the meter.

3.9 The procedure for mixing the salt solution is straightforward, but there are one or two potential sources of error that could catch the unwary. Even if packed in dry conditions salt in a plastic bag adheres to the side. It is advantageous to wash the bag in the bucket to ensure complete solution. A sheltered and level site is needed for mixing to prevent windblow of granular salt and to prevent slopping. The bucket should not be overfilled with water, as water level build-up occurs during stirring. Stirring is a useful check on complete solution, as granular salt will collect at the centre of the bucket. Changing the direction of stirring at frequent intervals will help to distribute the salt more evenly. The visual check on solution, by waiting for the water to clear, may be difficult in turbid conditions. Dissolving common salt can take a considerable amount of time (5-10mins), especially in low temperatures and where a large amount of salt is being added (>1kg). With larger amounts of salt it may be desirable to mix up two buckets and to pour at the same point in the stream. In any case it is wise to limit the concentration of the solution in the bucket to about 200g/l, so that the density of the solution is not an obstacle to natural mixing with the stream water.

The instruction booklet recommends (page 8) that the salt is injected over a 15-second period. Though injection over a specified interval is not a requirement of the method, a suggestion like this can be useful as a means of avoiding splashing of the salt solution and the formation of a pool of brine at the bottom of the stream, which could take time to join the main flow. A slow injection also gives a last-minute opportunity to observe and disperse any remaining salt crystals.

4. Display of results

4.1 The menu display during the setup procedure is clear and informative and leaves little scope for error. Calibration using the standard 1413 $\mu S\ cm^{-1}$ solution provided with the unit is virtually automatic and simple to perform, and the calibration is held between runs. We understand that correction for temperature is dealt with internally, using the temperature probe fitted to the electrode, so that this standard solution can be used at any temperature. However, we would recommend gentle stirring or agitation of the solution to achieve a constant temperature during calibration. Perhaps the only item that could be improved is the means of entering the weight of salt to be added for the test. Using up/down buttons, this increments by 1g at a time and is painfully slow. Where consecutive tests are being carried out on the same river this clearly only has to be altered whenever flow has changed sufficiently to warrant a change in weight of salt used. However, when moving between streams of different size and discharge, this would have to be done more frequently. There seems little point in the increment being as fine as 1g, as the tracer is usually weighed and bagged prior to the gaugings into set multiples of, say, 100g or 250g. Thus an increment of 50g on the button would be of adequate precision and much quicker to use. On the other hand if 1g discrimination is seen to be an advantage perhaps a means of changing individual digits on the display could be incorporated.

4.2 The display during the test is informative, giving elapsed time since the rise of conductivity above background, the current conductivity (which can be logged manually if required), and the initial background conductivity for reference and to allow the operator to recognise the approaching end of the test.

4.3 At the end of the gauging a display of results remains fixed until the unit is reset, giving plenty of opportunity to record these on paper. The display usefully gives background conductivity, maximum conductivity (which is essential to check that sufficient conductivity enhancement has been achieved), total elapsed time for the gauging and average flow in litres sec^{-1}.

Unfortunately, for the purposes of assessing the operation of the machine, in its present configuration there is no interrogable memory in which to store the individual conductivity measurements that are used to calculate flow. Because the shape of the conductivity curve tells us so much about flow characteristics and variation within the channel, such a feature would also be useful for analytical purposes, such as optimising mixing lengths, estimating time of travel and dispersion characteristics, and quantifying dead zones. At the moment valuable information is being lost after the unit is reset.

It was not clear when performing manual checks on the test data whether the conductivity is displayed in real time, and at what point the unit starts its integration of conductivity readings. The full display of time and conductivity appears a few seconds after the conductivity starts to rise, but we are assured by Dulas that the integration starts immediately after a stable background concentration has been found by the instrument, and that the displayed conductivity is updated at 1 sec intervals.

The amount of tracer added seems also to have an effect. During runs with low peak conductivities (i.e. too little tracer) the initial startup response is slower, as clearly it takes longer to achieve a given percentage increase in conductivity and so trigger the instrument. This does affect the results of gaugings that do not achieve the recommended peak conductivity, and the user should be strongly discouraged from placing too much reliance on the quantitative results of preliminary trials with small amounts of tracer.

It is appreciated that the above comments and suggestions may be only of specialist interest, and they certainly do not detract from the usefulness of the instrument in its present form for general use. However the provision of data storage could perhaps be considered as a modification, enhancement or option in future.

5. Aspects of methodology

The salt gulp method is a well known and often used technique that is theoretically capable of giving accurate and precise estimates of flow in small, turbulent streams. However there are combinations of circumstances that occur during gaugings that can prejudice this accuracy, some of which are inherent in the method and cannot easily be corrected, and some of which can be allowed for but tend to make the method more cumbersome and less user friendly. The problem of trying to automate the method, as with the *FlowStream*, is that all the potential drawbacks have to be predicted for the method to be infallible. This only highlights the importance of saving the raw conductivity data in order to provide corrected estimates during post-processing. Such problems include:

i. Definition of the point in time at which the concentration of salt rises above background, signalling the arrival of the leading edge of the salt wave. Generally, the more the salt concentration in the stream is enhanced, i.e. C_p/C_b is large, the more clear-cut is the starting point of the initial rise.
ii. Objective assessment of the point in time that background conductivity is re-attained. As with any automated system, problems arise with the *FlowStream* because there is a predetermined threshold of uncertainty for attainment of background level which can be less than the 1 $\mu S\ cm^{-1}$ discrimination on the meter. Therefore, a 1 $\mu S\ cm^{-1}$ reduction in the background conductivity over the gauging would result in the curve never closing and the test having to be aborted. This occurred on two occasions during the test gaugings (see section 6). The problem is less likely to occur if, as for (i), a large C_p/C_b ratio is ensured, or if the stream being gauged has a high background conductivity.
iii. Storage in the system attenuates the wave, tending to reduce peak concentration, and hence the C_p/C_b ratio, so lengthening the tail and introducing the problems outlined in ii..
iv. Perhaps most importantly, because ultimately it is salt concentration not conductivity that needs to be integrated over the time base of the salt wave, the calculation by the *FlowStream* depends on knowing the conductivity v. salt concentration relationship.

The relationship can be found in the literature for both NaCl or KCl, and will generally hold to a reasonable degree of accuracy whatever the source of tracer and the impurities contained (for instance table salt or cooking salt can be assumed the same). However, the relationship is heavily dependent on temperature. The *FlowStream* incorporates a temperature compensation polynomial that produces a good fit over most of the range but starts to deviate below 3.5°C, a range that is not uncommon in upland streams in the winter months especially during snow melt events. It is thought that this deviation is not sufficiently serious to compromise the results obtained.

6. Test gaugings

In order to make an objective assessment of the *FlowStream*, three sets of gaugings were carried out in the Plynlimon catchments. Two of these were on the Afon Hafren tributary of the River Severn, draining a catchment area of 3.58 km^2, and one was on the Upper Hore tributary of the same river draining an area of 1.78 km^2. Both sites are fitted with flow gauging structures of the critical depth flume variety, especially modified to cope with high sediment loads in steep streams.

When first built these flumes were of an original design and not much was known about how they would perform in practice. In the event, various checks on the calibrations of the Hafren flume highlighted some problems which have since been overcome with the development of composite calibrations, taking the most reliable features of theoretical, dilution gauging, current metering and temporary structure ratings. The Upper Hore flume was built at a later date, 1985, and has also been subject to rating checks using traditional impeller meters and electromagnetic meters. Unfortunately these neither agreed with each other nor with the theoretical rating for the structure, so the whole exercise was rendered inconclusive. It is still suspected, however, that the theoretical rating of the structure may be underestimating flow by up to 10% in the low to medium flow range, largely because there is asymmetrical flow in the approach section of the flume in the mid-range.

The test programme has therefore put the *FlowStream* through its paces in a number of senses:

i. internal consistency (repeatability) at an approximately constant flow
ii. at two different points in the flow range of one stream
iii. against a flume with a reliable calibration
iv. as an independent check on a flume with an unreliable calibration, where there is evidence from other independent techniques of problems with the theoretical ratings.
v. in a gently meandering channel with small scale riffle and pool sequences.
vi. in a sinuous channel with an exaggerated waterfall and plunge pool profile.

6.1 Hafren gaugings

The first set of gaugings were carried out upstream of the Hafren Flume on 8/11/96 during recession flows of 421.88 l sec^{-1}. The width of the channel was estimated at 4m and an injection point selected on top of a riffle c.80m upstream. The sampling position was also on a riffle, but it was ensured that there was no aerated water around the conductivity probe, the probe being held in place just above the bed with a small boulder. An estimated average depth of 0.3m was used to determine the cross sectional area. From the table in the manual the weight of salt was read as 500g for a cross sectional area >1m^2 and a background conductivity of 0-100 (actually 45) µS cm^{-1}. The pulse took about 2 minutes to arrive, the conductivity was back to background 3 min 50 sec later at which point the meter automatically stopped the gauging and calculated the flow.

The peak conductivity of 67 µS cm^{-1} was only 149% of background, indicating that too little salt had been used. The calculation shown in section 3.5 was used to assess the optimum weight of salt, indicating the need for >1000g salt. A weight of 1250g was selected, being the next highest multiple of the 250g bags available.

Subsequently, three further runs were carried out, two using 1250g of salt and one using 1000g. Manual readings were taken, and the results plotted in figure 6.1. The individual gaugings have been corrected in the vertical scale so that a comparison can be made between the curves relating to differing tracer quantities. These indicate a very close agreement between gaugings using the larger amount of salt, but a slight discrepancy, particularly in timing, of the initial gauging using too little salt. The flow values calculated by the meter are shown in table 6.1.1, alongside estimates from a manual analysis of the conductivity data (using the conductivity v. salt concentration relationship supplied by Dulas Ltd. and incorporated into the *FlowStream*), and the interpolated flow from stage readings taken over the study period at the Hafren Flume.

Table 6.1.1 Results of the higher flow gaugings on the Afon Hafren

Flume Stage (mm)	Flume Flow (l sec^{-1})	Salt added (g)	Cond. Backgr. (µS cm^{-1})	Cond. Peak (µS cm^{-1})	Manual Flow (l sec^{-1})	Meter Flow (l sec^{-1})
501	425.43	500	46	67	495.30	481.90
500*	423.91	1250	45	101	445.47	442.86
499*	422.38	1250	45	101	437.69	434.19
497*	419.34	1000	45	89	446.05	441.84
Mean*	421.9				443.07	439.63
± 2SE					5.39	4.89
± 2SE(%)					1.22	1.11

From these results it seems clear that the internal consistency of the *FlowStream* values is good giving a mean flow from the three gaugings (with the optimum tracer weight) of 439.63 $\pm$ 4.89 l sec^{-1}, i.e. 95% confidence limits of 1.1%. This value is 4.2% higher than the mean flow from the Hafren Flume over the same period.

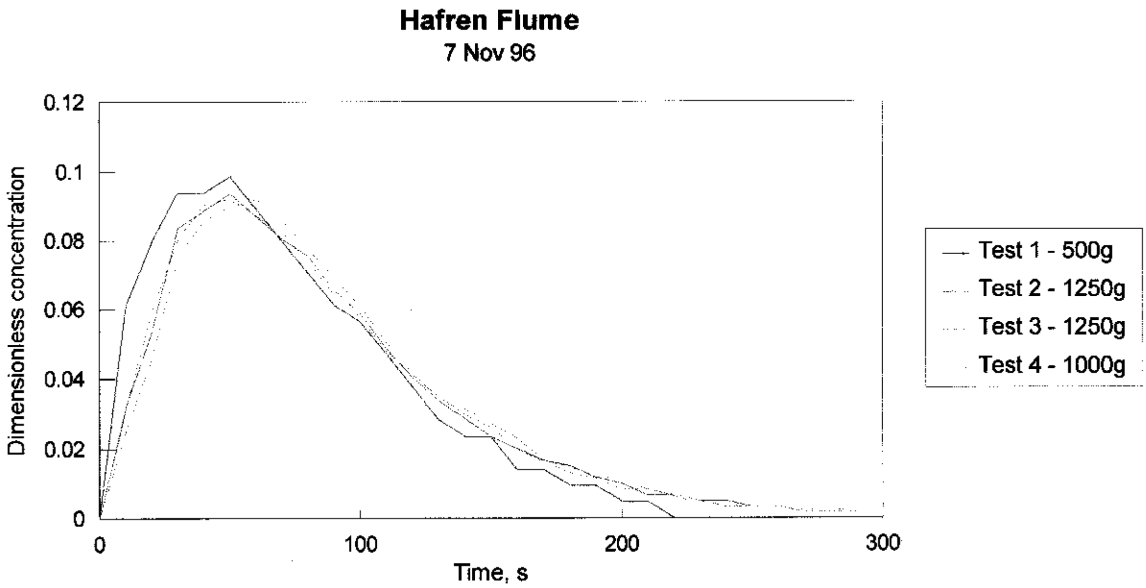
A second set of gaugings was performed at the Hafren on 12/11/96 (table 6.1.2 & fig. 6.1) at a flow of 175.54 l sec-1 which gave a mean value of 172.72 $\pm$ 0.22 l sec^{-1}, which is precise to within 0.13%. This value is closer to the Hafren Flume flow than the original gaugings, being low by only 1.6%.

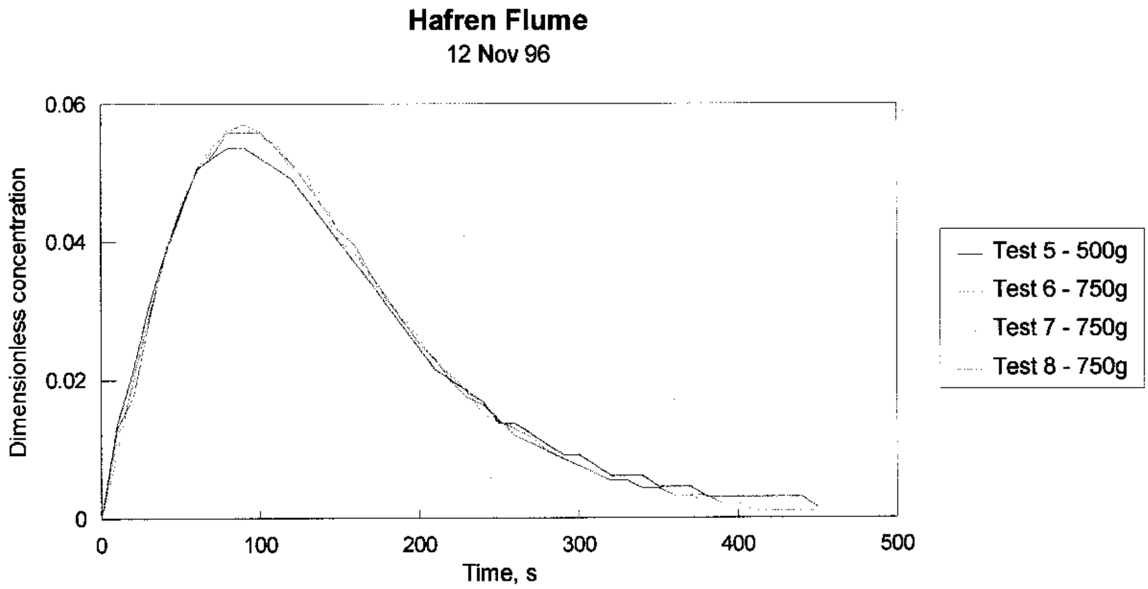
Table 6.1.2 Results of the lower flow gaugings on the Afon Hafren

Flume Stage (mm)	**Flume Flow (l sec^{-1})**	**Salt added (g)**	**Cond. Backgr. (µS cm^{-1})**	**Cond. Peak (µS cm^{-1})**	**Manual Flow (l sec^{-1})**	**Meter Flow (l sec^{-1})**
309	175.9	500	39	74	163.92	150.26
309*	175.9	750	40	92	175.19	172.61
309*	175.9	750	40	93	172.54	172.57
308*	174.83	750	40	92	173.79	172.99
Mean*	175.54				173.84	172.72
$\pm$ 2SE					1.53	0.22
$\pm$ 2SE(%)					0.88	0.13

The performance of the *FlowStream* is good at the higher flow level and excellent at the lower, and much better than the rather pessimistic value of $\pm$10% given in the manual, but the reasons for the better performance at the lower flows remain slightly mysterious. The graphs of the conductivity curve indicate that mixing was very good for both sets of gaugings. The temperatures at which the gaugings took place are similar and well above the threshold where the conductivity/concentration relationship starts to break down. The explanation may lie in the following:

i. There has always been a problem with the rating of the Hafren Flume in its mid-range, as explained earlier in this section, and the discrepancy may be only partially in the *FlowStream* result, and possibly not at all.
ii. The *FlowStream* is recommended for use in flows of less than 1000 l sec^{-1}, presumably because of the inordinate amount of salt required at higher flows than this, and the difficulty of dissolving the salt in cold water. It is possible, but unlikely, that the 1000 - 1250g of salt used may not have dissolved fully before injection, resulting in artificially low concentrations being measured and the flow overestimated. This would be less likely to happen at the lower flow.
iii. Perhaps most likely, if indeed the error is in the *FlowStream* result, is the reliance of





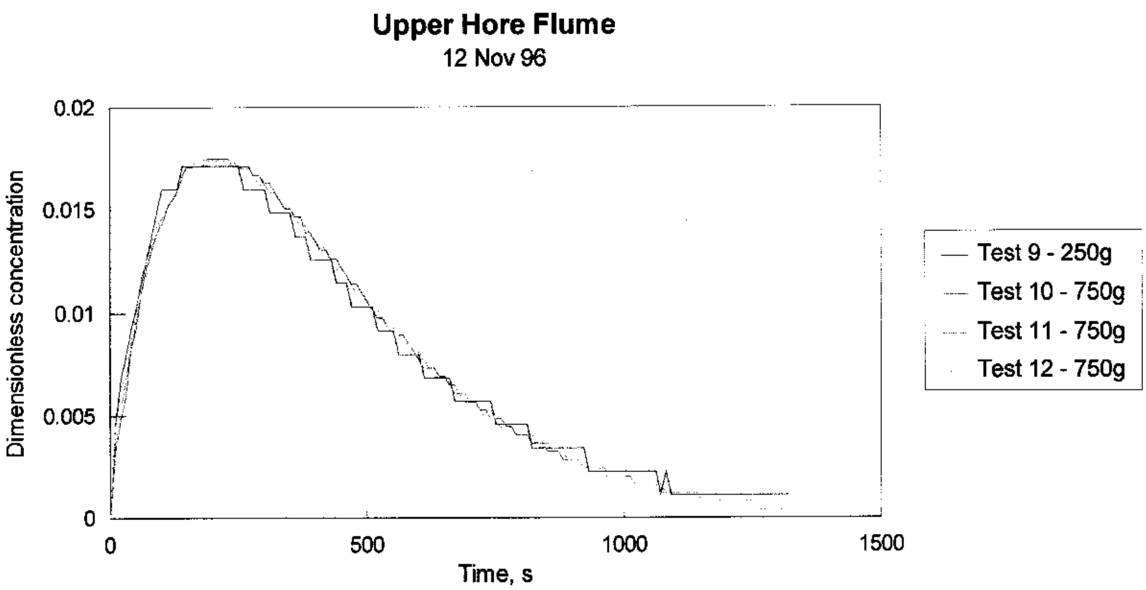


Fig. 6.1 Conductivity-time curves

the method on a laboratory derived conductivity/salt concentration relationship and temperature compensation equation, either of which may not hold in the field, and the assumption that the conductivity or salt concentration of the mixed tracer does not need to be checked in the field prior to the injection. Many conductivity meters do not provide temperature compensation below 10°, which may also be an indication of unreliability below this temperature. This hypothesis could be tested by performing another series of tests at a similar flow when the water temperature is >10°.

6.2 Upper Hore gaugings

Four gaugings were carried out on 12/11/96 on a steep, rocky reach of the Afon Hore, upstream of the Upper Hore flume at a flow indicated by the flume of 57.71 l sec^{-1} (table 6.2 & fig. 6.1). The initial gauging using the table in the manual resulted in a gross underestimate of the amount of salt required, largely because the cross sectional area of flow at the sampling point was small compared to the same dimension in the plunge pool in the measuring reach, and also because the storage of the plunge pool caused a large reduction in the peak conductivity. The weight of 250g was increased threefold to 750g in the three subsequent tests, and very good agreement was found in the flow values obtained. The mean flow of 63.47 ± 0.12 l sec^{-1} is precise to within 0.19% but is greater than the flume flow by 10.0%.

This large discrepancy is almost certainly down to the poor calibration of the Upper Hore flume in this range of flows. The flume is known to exhibit asymmetrical flow at certain stages due to the less-than-ideal approach conditions down the ramp which will cause a deviation from the theoretical calibration. Attempts to provide an alternative calibration have so far foundered on the difficulty of finding agreement between the alternative methods using impeller and electromagnetic current meters, though both indicated to varying degrees that the flume underestimates flow.

Table 6.2 Results of the gaugings on the Upper Afon Hore

Flume Stage (mm)	**Flume Flow (l sec^{-1})**	**Salt added (g)**	**Cond. Backgr. (µS cm^{-1})**	**Cond. Peak (µS cm^{-1})**	**Manual Flow (l sec^{-1})**	**Meter Flow (l sec^{-1})**
117	57.97	250	38	53	61.20	58.64
117*	57.97	750	38	82	65.36	63.46
117*	57.97	750	39	83	65.27	63.35
116*	57.2	750	39	82	65.01	63.60
Mean*	57.71				65.21	63.47
± 2SE					0.21	0.12
± 2SE(%)					0.32	0.19

7. Conclusions and recommendations

7.1 The *FlowStream*, together with the gauging method outlined in the accompanying instruction booklet, has been tested in the field in the Plynlimon experimental catchments, by carrying out repeated gaugings at two sites, at flows ranging from 60 to 420 litres/second. No difficulty was experienced with the method or the operation of the instrument. Results were very encouraging, demonstrating excellent repeatability. For the three gauging exercises, 95% confidence limits on the mean flow measured by the *FlowStream* were $\pm$1.1%, $\pm$0.13% and $\pm$0.19% respectively.

7.2 Close agreement was found with flows from the steep-stream gauging structures that form part of the Plynlimon catchment network, all within the pessimistic potential accuracy of $\pm$10% given in the manual. For the Hafren reach the agreement was extremely good for the lower flow gaugings (-1.6%), and acceptably good for the higher flow gaugings (+4.2%). The Upper Hore flume gave flows 10% lower than the *FlowStream* but this discrepancy can be explained more by the inadequacies of the flume rating at these flows than by any problems with the *FlowStream.*

7.3 The manual recommends use of the *FlowStream* only in what appear to be ideal conditions, but with care the method appears to be far more robust than it is being given credit for. In particular, the method does appear to be viable in reaches containing storage in pools, which is fortunate as such pools, a common feature of mountain rivers, cannot always be avoided. The only drawback is that gaugings will take considerably longer, reducing the number that can be achieved in a given field session and increasing the likelihood that the spread of results obtained will be compounded by a change in discharge.

7.4 In terms of its technical specifications the *FlowStream* could be improved in a few areas:

i. The plug and socket connection between the probe and meter needs some attention, especially a key for the bulkhead socket to prevent rotation.
ii. The method of keying in salt quantities could be speeded up, either by incrementing in larger quantities or by providing a means of altering individual digits. Larger increments do however imply that salt is pre-weighed in suitable quantities, e.g. 250g, 500g and 1000g.
iii. For manual checks, or scientific use of individual conductivity readings, e.g. for time of travel measurement, it would advantageous to have one decimal place precision of the display. It is probable that calculations within the instrument are using higher precision measurements than are displayed.
iv. As a possible improvement to the existing unit, or as an extra cost option, the storage of individual conductivity values, in such a way that they can be retrieved by the user post-gauging, could be considered.

7.5 It would be worth stressing that the table of salt weights given in the manual is not a substitute for the initial gauging which gives important information towards optimising the quantity of salt for subsequent gaugings. However, if the peak is outside the optimal range, it could be misleading to include this initial gauging in the calculation of the mean discharge.