REPORT TO BE SCANNED

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Calibration of Gauging Stations Using Portable Ultrasonics. Supporting Documentation

R&D Technical Report W6/i646/1

Calibration of Gauging Stations Using Portable Ultrasonics

Supporting Documentation

Project Record
W6/i646/1

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Statement of use
This project record is aimed at those interested in the measurement of river flows using ultrasonic (time of flight) gauges. It provides supporting documentation to the R&D Technical Report W189 who is a practical guide for use by hydrometric staff and managers, based on field experience and the analysis of the results.

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EXECUTIVE SUMMARY

This Project Record is a collation of the material produced during the course of the Environment Agency R&D project W6/i646, Calibration of gauging stations using portable ultrasonics. The Record contains material which cover three main sources:

Section A

Reprints of the eight Progress Reports produced by the research contractor during the course of the project. These are largely as originally produced but with the contractual information removed where appropriate.

Section B

Site Reports which summarise the work completed at the six gauging stations used during the course of the project, together with any supplementary information relating to these. These reports form the basis of the analysis presented in the Environment Agency R&D technical Report W189 which accompanies this document.

Section C

Other material relevant to the project. This includes Agency data and comment, together with details of the equipment used for the project, and similar material that is produced by alternative manufacturers.

A separate disc accompanies both this Project record and the Technical Report, and contains the data collected at the gauging stations.

KEY WORDS

Ultrasonic gauge, time-of-flight, gauging station, flow measurement, twin-path, multi-path, rating curves, stage-velocity relationships, stage-discharge relationships, non-modular flows.

PROGRESS REPORT 1 - SCOPING STUDY (24/11/95)

1 INTRODUCTION

This Scoping Report builds on the submission by Scotia Water Services to carry out NRA R&D Project B01(95)01, Calibration of gauging stations using portable ultrasonics. Whilst it will summarise the project objectives and progress to date, it will also concentrate on the proposed methodology to enable the Authority to assess this before the field work commences.

Of the three options outlined in the tender, the Authority selected the one which will allow evaluation of the equipment under truly portable conditions, where the gauge, transducers, cables and all ancillaries are moved from site to site, and under 'mobile' conditions where only the gauge is moved and transducers, cables etc are permanently installed at a number of sites. This will allow the equipment to be evaluated both for 'one off' studies, such as those associated with data collection for modelling work, and routine calibration of gauging stations and their associated structures.

2 PROJECT OBJECTIVES

The PID included in the tender document listed 10 different specific objectives of the project. Whilst these objectives will all be addressed during the course of the project, it is perhaps useful to group some of them together into similar work areas and to expand on others as follows:

(1) To test and report on the performance of the ultrasonic gauges at a range of sites under mainly high flows. This will include using the instruments at both standard and non-standard structures, under modular and non-modular conditions. The accuracy of the gauges in measuring both velocity and discharge will be assessed, along with determining any areas of uncertainty in the results. Similarly, different operating conditions shall be assessed, along with different methods of mounting the transducers.

(2) To use existing ultrasonic gauges in a manner which replicates the twin path gauges, and to use the results from these, together with output from (1) above, to determine an optimum configuration (if one exists) for the twin path gauges. By using logged data it may be possible to use historic data from the existing gauges, thus ensuring that suitable high flow data are available.

(3) On completion of the field assessment, practical problems of using the gauges, along with limitations (practical, financial and due to safety reasons) shall be identified. Where feasible, a standard practice (or practices) for using the gauges in a portable context will be recommended. Having completed this, it will then be possible to assess typical costs of using the gauges, based on capital, operating and manpower resources.

(4) Finally, during and on completion of the Project a number of reports will be produced. The Quarterly/Interim Reports shall give details on progress made, including any Site Reports as field tests are completed at each site. The final output is to be a Project Record, which will draw together the results from the different sites, an R&D Note which will provide a summary of the project findings and a 'best practice' for using the gauges.

3 PROGRESS TO DATE

Given that the contract was not awarded until the end of October, we have concentrated efforts to date on preparation for the field assessment of the gauges. We feel it is beneficial to maximise our chances of commissioning the gauges as early as possible to ensure that the greatest potential amount of data is collected. At the same time, we have initiated the data collection from other NRA Regions, although we do not expect to complete this until the gauges have been installed.

3.1 Equipment

Following the Project Inception Meeting in Warrington on 27th October, an outline order was placed with Peek Measurement for two 1408 gauges and ancillaries. Subsequently, a visit was made to Peek's premises in Winchester on Thursday 2nd November to discuss the project, procure the gauges, transducers, mounting blocks, cables and software, and to receive a day's training in the use of the 1408, concentrating mainly on the software configuration and operation.

As a result of the meetings a number of issues were resolved regarding the field assessment, including the assistance that is to be given by Peek personnel in installing the gauge at the first two sites. One area of concern is the dependence Peek place on the use of an oscilloscope in setting up the transducer paths. Whilst it is less important in a twin path gauge such as the 1408, Peek still consider it to be necessary. We thus propose to add this to the field evaluation studies, most likely in the second winter. A 'scope will be used for the first winter season to maximise data returns from the first two sites.

Peek have agreed to release software previously developed for another client that increases the flexibility of the parameters used to calculate the discharge. This effectively allows parameters that are usually set as constants in the 1408 software to be used as variables. This came about because we are aware of problems associated with 'vertical dead zones' u/s of a weir, where the water layers close to the river bed are often stationary or near stationary. We are aware that the project is not to focus on the properties of the gauge manufactured by a specific manufacturer, and will endeavour to work within standard configurations wherever possible. To ensure that this is the case, we now also propose to approach other manufacturers of twin path gauges to try and determine how their gauges determine discharge from velocity measurements. If methods are found to differ (this is thought to be unlikely) we can evaluate the different methodologies should the Authority wish.

Whilst Peek have not used the Psion as a data logger themselves, they were able to confirm that in cases where they know the Psions to have been used they have been found to be reliable. Peek have offered to load and test the 1408 standard software and reprogram the additional software for Psion use, at no extra charge.

One point that we would wish to make regarding the equipment procurement is that since the Tender Submission was made the Psion II has been discontinued and is thus very difficult to get hold of. Peek have agreed to us supplying them with Series 3 Psions instead, provided the Authority agree to this change in specification. We do not envisage any significant change in costs given current prices, even though the instruments have a higher specification.

Peek plan to ship the gauges and equipment by Friday 15th December. Flow conditions permitting, this should allow us to install both gauges before the end of the year, although it may not be possible to get Peek personnel to assist with the commissioning until the beginning of January. Peek have already supplied us with sample mounting blocks and the designs for the mounting systems are underway.

3.2 Data Collection/Literature Review

Following the earlier information gathering exercise by the Project Leader we have written to all NRA Regions seeking their assistance with the project. We are attempting to determine how many existing gauges have stored path data to try and evaluate different path configurations, along with looking at the performance of the gauges under simulated 1408 set-ups. Regions have also been asked to supply copies of any reports/papers they have produced relating to the time of flight gauges, and in light of the oscilloscope dependence mentioned earlier we have asked whether each Region has suitable equipment and trained personnel.

A combination of written responses, follow-up 'phone calls and the results of the earlier enquiries by the Project Leader suggest that the following information/data may be available from each identified Region:

Severn-Trent

We have both received a written response from Jim Waters and discussed the Project with him. Jim is very much of the opinion that it would be useful to the project if we were to meet so that he can pass on the Severn-Trent experiences by word of mouth - like many Regions he says that Severn-Trent are too busy being Hydrologists to write academic papers. Jim outlined their results from using reflector systems, advising that a report has been written on this, and has already offered some sites for the second winter season. Finally, Severn-Trent no longer have any field competence in the use of oscilloscopes - they leave that side of things to Peek.

Thames

Whilst Thames Region have carried out detailed assessments of gauge performance within their Region they, like many others, do not have a documented record of these studies.

George advised that it may be possible for the Region to collect suitable path velocity data for the project via RAR2, as well as path velocity data from their Kingston gauge that is logged on a Psion.

Thames Region have the use of an oscilloscope, and a technician familiar with its operation.

Southern

No data/reports are available, and no logged or real-time path velocity is available (although RAR2 may change this). Technicians are experienced in the use of an oscilloscope if needed.

Northumbria & Yorkshire

No specific studies have been carried out and consequently there are no written papers or reports. However, the Region has considerable experience in the use of the gauges and has quantitative data to support their experience in finding some limitations to the use of the gauges, mainly relating to path length and suspended sediment size/concentration. Peter Towlson suggested that it would be useful for us to visit him so that this experience could be passed on.

Some of their gauges have limited (64k) data backup of path velocities on barrel memory data loggers - whilst this data is in a very unfriendly ASCII format, it could be used if needed to look at path velocities during an event. However, Peter feels that RAR2 will offer greater potential for this and is prepared to collect data should we wish.

Finally, some of the hydrometric technicians are experienced in the use of a 'scope and Peter agrees with Peek that it is essential to use one when setting up by path lengths.

Anglian

Some reports/papers on studies already carried out may be available within Anglian Region and Mark Whiteman has agreed to research this further. Any literature is most likely to apply to their North and Central Areas.

At present, none of their gauges log path data, although an Accusonic gauge does offer the facility. However, RAR is again a possibility, and if so, some of their gauges (such as Shillingthorpe) would appear to be suitable sites to use to collect additional data.

Mark was not aware of any technicians being familiar in the use of a 'scope, and commented that they would generally use Peek technicians to set up the gauges and solve any problems.

Welsh

The first Region to respond, Steve Mayall initially suggesting that no data or reports were available, either historically or in real time, and no technicians have 'scope experience. However, after a follow-up 'phone call, Steve mentioned that they are beginning to routinely check individual path velocities and that a record could be made of these for the project if required.

South-West

We have not yet received a response from the South-West Region. Given that, according to the Project Leader's initial enquiries, they do not have any ultrasonic gauges, it is unlikely that they will be able to make a significant input to the project.

North-West

As with other Regions, North-West are not aware of any reports that have been written regarding either the evaluation or performance of the gauges. However, they have maintained records of path velocity checks (1-minute) that are made at regular intervals. Finally, they have a technician who is familiar with the use of an oscilloscope.

From these responses it can be seen that, with few exceptions, there are little data or reports available within the NRA that would be of direct assistance to this project, and that oscilloscope familiarity is variable from Region to Region.

However, the responses from the individual Hydrometric Group Members was enthusiastic, with the general impression being one of a desire to provide assistance wherever possible. As mentioned above, a number of Regions (especially Northumbria & Yorkshire and Severn-Trent) felt it would be useful to discuss their experiences in using different gauges, and we feel that this would be a valuable exercise to support the literature review which is currently looking to be rather sparse. We would thus propose that a trip is made to both Severn-Trent and Northumbria & Yorkshire Regions to discuss their studies/experiences of using ultrasonic gauges, possibly combining this with some site evaluation in early 1996 (see later). Whilst our tender allowed for the time to be spent on data collection, it did not budget for travelling/subsistence costs as it had been envisaged that data would be readily available. We would thus seek approval from the Authority to carry out these visits as part of the project.

Outwith the Authority, the literature search for material relating to ultrasonic time of flight gauges has commenced. Initial results suggest that there will be very limited material available from within the UK and the search will thus be expanded to include a world-wide perspective. It is also our intention to approach the manufacturers of gauges within the UK to try and obtain any reports they may have.

With regard to individual path velocity data, there again appears to be little historic data available, but the officers from each Region were equally enthusiastic about collecting such data if requested. Whilst this clearly prevents the initial instrument commissioning being based on analysed, historical data, it would allow individual profiles to be studied as the project progresses. We thus propose to request Regions with the new version of RAR to collect suitable data over the coming winter on our behalf.

3.3 Site Selection

Following the Project Inception Meeting a desk study was made of the gauging stations operated by the NW Region and included in their "Summary Details of Flow Measurement Stations" produced in 1991. In addition to this, the current calibration classification codes were also studied to try and select sites with a good (LF2, MF2, HF2) or excellent (LF1, MF1, HF1) rating curve.

A total of three trips have been made to look at potential sites. The sites visited are as follows:

Central Area

Scorton - Wyre
Carvers Bridge - New Mill Brook
U/S A6 - Brock

Northern Area

Sprint Mill - Sprint
Mint Bridge - Kent
Sedgwick - Kent
Newby Bridge - Leven
Low Nibthwaite - Crake
Duddon Hall - Duddon
Duddon Bridge - Duddon
Thirlmere - St Johns Beck
Pooley Bridge - Eamont
Greenholme - Irthing

The stations marked in bold are, we feel, stations that might be used for the 1996/97 winter season. Carvers Bridge offers a narrow, straight channel, suitable for using the 1MHz transducers, although the site visit did not reveal any obvious instrumentation at the site. The Kendal duo of Sprint Mill and Mint Bridge are both sites where, according to the Area

Manager, using the 1408 to calibrate the structures would be beneficial, whilst Sedgwick offers a good calibration, secure site and cableway. Duddon Bridge may allow the instrument to be evaluated under 'backing-up' conditions, something which, to date, has not been included in the scope of the project. Finally, both Pooley Bridge and Newby Bridge are sites where the instruments could be evaluated at a compound structure, both sites having large width channels. Were it not for the fact that neither station has a cableway, and is thus unsuitable for evaluating the velocity measurements, they might have been used as sites for the first winter season.

We propose that Greenholme and Low Nibthwaite are the stations used for the first winter season. The reasons for this are as follows:

(1) Both stations have an LF1, MF1, HF1 classification.

(2) Both stations have an artificial control structure (both non-standard V-controls).

(3) Both stations have a cableway u/s of the control.

(4) Both stations offer good security, with reasonable access.

(5) It is possible to travel to either station within one and a half hours of leaving base, thus maximising our chances of being on site during high flow conditions.

(6) This has been further enhanced by the fact that whilst Greenholme is an open channel river site which is relatively quick to respond due to the steep tributaries, Low Nibthwaite should be much slower to respond as it is below Coniston Water which will tend to attenuate any high flow events. Thus, when/if such events occur, we can travel first to Greenholme (< 1 hour) before moving on to Low Nibthwaite. This is an especially important factor for the first winter season when we intend to concentrate on evaluating the performance and limitations of the equipment.

(7) The sites offer a large difference in channel width, with Low Nibthwaite falling on the border between the 1MHz and 500 KHz transducer requirements (we are currently awaiting data to confirm this) whilst Greenholme is a much wider channel.

(8) High flows are generally contained within banks at each station, although Greenholme has been known to flood in the past.

(9) Both stations offer a wide range in stage, ensuring that different transducer configurations can be evaluated.

(10) Whilst Greenholme has a very straight and uniform approach channel, Low Nibthwaite has a less straight approach (although the channel at the station itself, being stone walled, is both straight and uniform) which will allow us to evaluate cross-path configurations.

(11) Finally, whilst the water at Low Nibthwaite is generally clear, having low suspended sediment concentrations due to it being below the lake, that at Greenholme is far more silty, particularly during high flows. This will allow us to begin looking at sediment effects on gauge performance, further assisted by the fact that the Area Water Quality department have sampling sites up and downstream of the station.

Having selected these sites, we have requested further information from Ray Moore, the Area Hydrometric Manager (copy supplied to Project Manager). Ray has responded very quickly to our request, answering most questions within 24 hours; he and his staff are currently collecting the requested data and will be forwarding it to us by 11th December.

4 WORK PROGRAMME

4.1 Winter Season 1

The overall objective of the first winter season is to collect as much data as possible to assess the accuracy of the gauges, limitations of use, different configurations and operating limits. Whilst the majority of this will be obtained from the field evaluations at Low Nibthwaite and Greenholme, data will also be collected from existing gauges (by their respective Regions) via the RAR2 software to allow evaluation of different path configurations. The planned methodology/programme is set out below.

December 1995

~ Request data to be collected from NRA Regions of individual path velocities.
~ Design and fabricate mounting systems for Low Nibthwaite and Greenholme (complete by 18.12.95).
~ Receive further data from Northern Area, NW Region, to allow determination of path lengths at initial sites.

~ Progress meeting in Warrington to discuss Scoping Report and agree/confirm project programme.
~ Take delivery of gauges from Peek, week beginning 18.12.95.
~ Install conduits and mounting systems at initial sites (weather conditions permitting) and liaise with Area staff to agree location of gauges.
~ Install gauges and commission if possible.

January 1996

~ Complete installation/commissioning of gauges, using Peek staff if necessary.
~ Commence field evaluation of the gauges.

The remainder of the winter (envisaged to be up to the end of April 1996) will be involved with the field evaluation of the gauges. As this will be dependent on weather/flow conditions it is not possible to determine a timetable in advance. However, we can confirm that a total of 36 man days are planned for this part of the project, and that Quarterly and Interim Reports are to be produced for 29th February and 31st May respectively. It is envisaged that the Interim Report will contain the two site reports, with the results from the first winter season. The evaluation work that is planned is as follows:

(1) To confirm that the equipment operates as specified in Table 7.1 of the tender document.

(2) To assess the performance of the equipment in determining velocity and discharge at both stations by comparison with cableway and rating curve data. Ray Moore has confirmed that NRA staff will be available to assist with the cableway gaugings, allowing us to concentrate on the gauges themselves. We intend to concentrate initially on the velocity measurements as, if these are inaccurate, it will clearly not be possible to determine discharge no matter how good the processing software is. Conversely, if the velocity measurements are good, and it is only the software that is at fault, then the gauge will obviously have potential even if a problem needs to be solved.

(3) To operate the gauge at Low Nibthwaite with both crossed and parallel paths to assess the benefits and disadvantages of this approach.

(4) To assess the practicalities of operating the two paths at different levels throughout an event or season. As mentioned in our tender document, this will (in theory) allow results similar to those from a multi-path gauge to be derived. If this is to be true it will

depend to a certain extent on the stability of the river bed at each site and the presence/absence of any hysterisis. Given the very different nature of the two sites, we intend to carry out the 'during an event' evaluation only at Low Nibthwaite where safe access can be obtained from kneeling on both banks and adjusting a bracket that can slide up and down the mounting plate. Due to the sloping banks at Greenholme it will not be possible to safely do this during an event (cross-channel communications will also be harder) so we intend to alter the transducer levels on a week to week or event to event basis. By working in this way it will be possible to compare both approaches, thus allowing the practicalities of using either method to be assessed.

(5) By altering the levels of the transducers at Greenholme we also hope to begin determining some of the limitations of the gauge with regard to suspended sediment concentrations. As mentioned earlier, there are Water Quality sampling sites up and downstream of the station. By monitoring concentrations from event to event and having the transducers at differing levels, it may be possible to deduce conditions under which the gauge is unable to work. If so, how high do the transducers need to be to reach 'cleaner' water, or can the problem be resolved by reducing the path length (ie by increasing the angle to the direction of flow) and does this subsequently affect the velocity determination? We are aware that we may not be able to resolve this (potential) issue during the first winter season, but if it can be confirmed as an issue then it can be further studied during the second winter season. We costed this as a further option to the Authority after our initial tender.

(6) Whilst the Tender Document specified in Table 7.1 that the gauge must be capable of operating for not less than a week under battery power (which we shall be confirming) we consider that it would also be useful to begin looking at power/setup configurations. These include mains operation (at Low Nibthwaite - availability already confirmed by Ray Moore), using alternative battery supplies (costed as an additional option), operating two batteries in series and, potentially of greatest use when using the gauges under high flow conditions, switching the gauge on and off with a float switch. This final configuration is not one that was included in our initial tender but came about as a result of our discussions with Peek. We are currently exploring different aspects of this with Peek and will advise the Authority of the outcome. Clearly, its greatest potential benefit is using the gauge at remote sites for extreme events, but it should also help to reduce the risk of transducer failure.

(7) Once the field evaluations of performance/limitations are completed, we shall also evaluate different potential methods of routing the cables from the far bank to the

gauge. It is our intention to initially install a conduit at each site for the coaxial cables but, if time allows, we intend to look at the practicalities of routing the conduit in different ways (u/s and d/s of the weir, and across the main channel) along with the possibility of aerial routing if possible. This part of the evaluation will not be exhaustive, but will be added to during the second winter season when alternative sites are used.

Whilst the field evaluations are underway, and on completion of the winter season, the data from both the 1408s and other NRA gauges shall be collated and processed. Analysis of the data shall be started, looking initially at gauge performance but also attempting to seek an optimum (if one exists) path configuration for use under different conditions.

Potential sites for the second winter season will be visited and, as the project evolves, the final sites will be chosen on the outcome of the first winter's work.

One point we would like to make is that whilst Greenholme may appear to be an ideal site for a number of reasons, one of its potential strengths, namely the sediment loads at the site, may turn out to be a weakness if the gauge is found not to perform well under these conditions. Whilst accepting that this in itself is a result, we are aware of the need to collect as much data as possible during the first winter. We thus propose that if problems are found to exist (at either site) we move the gauge to an alternative. If this is the case, it is likely to be moved during February. Clearly, speed will be of the essence to maximise data returns, and we would seek an alternative site within the Northern Area of NW Region (possibly Pooley Bridge).

4.2 Summer Season

The work carried out in both the summer and second winter season will, to a certain extent, depend on the outcome of the first winter's work. The results will hopefully identify issues that need to be addressed during the second winter, along with possible optimum configurations for installing the gauge.

The overall objective of the summer season is to carry out preparatory work for the final flow installations, along with continuing the analysis of results from the first winter. In addition to this, we feel there is one item of field evaluation that could be usefully carried out during the summer months before (potentially) using the outcome for the second winter.

Our Tender initially included the evaluation of using the gauge as a reflector system during the first winter season. Following the Project Inception Meeting and subsequent discussions with Peek and other NRA staff, we have decided that it is not realistic to try and complete this work during the first winter. Whilst the potential benefits are high, the method is known to be quite difficult to set up, and generally it either works well or not at all.

We thus plan to carry out the initial evaluation of this method at Low Nibthwaite once the winter work is completed. Initially, it will not be necessary to work under high flow conditions as we will be seeking merely to explore the technique and its limitations. If the trials are successful then we hope to use one of the four winter sites in this way. One possible alternative might be to use reflected paths at Mint Bridge where there is a known vandalism problem and compare the practicalities and performance of such a system with a 'normal' configuration at Sprint Mill, a station with very similar physical characteristics to Mint Bridge. Another pairing that would allow a similar comparison is Pooley Bridge/Newby Bridge, with the added benefit that both sites would offer a compound structure for evaluation.

Once this work has been completed, and the final four sites chosen (or more if the project evolution dictates) work will commence on the installations for the second winter. It is planned to have two of the sites fully prepared, with transducers mounted and aligned, cables conduited etc, ready for the gauge itself to be connected up and commissioned. Whilst the mounting devices for the remaining two sites will be designed and fabricated, we are not presently able to state what preparatory work will be completed during the summer as this will, to a certain extent, be site specific. One possible option is to install the conduits and mounting plates in advance at one site, and to leave the other as a completely 'green field' site so that both methods of installation can be evaluated under winter conditions.

A Quarterly Report is to be prepared for 31st August which will include the results of the summer evaluations, any further analysis of the winter data, and a planned programme of work for the coming winter season.

4.3 Winter Season 2

Clearly, the further ahead one tries to plan the harder it is to be specific about the work that will actually be carried out. This is especially true for the second winter season where a large part of the work will depend on the findings of the previous phases.

The main objective of the second winter is to operate the two gauges at the four remaining sites using the methods/configurations developed from the previous seasons. It is intended to work under conditions which will closely reflect the use of the gauges by the NRA hydrometric staff so that the practical problems of application can be identified, along with assessing typical costs of using the equipment.

As briefly mentioned in the Summer Season programme, we shall be evaluating different means of using the equipment as a 'portable' gauge, ranging from merely moving the control box from site to site to carrying out a full, albeit temporary, installation of all equipment. This will hopefully allow us to recommend the most cost-effective method of approach for specific circumstances.

Whilst it is not possible to detail the exact methodology that is planned for this phase of the project, it is possible to list some of the items that we plan to look at, along with some of the potential site criteria we will be looking for in addition to those included in our Tender (pages 7 and 8). These include the following:

(1) The primary objective of the second winter season is to confirm that the results from the earlier evaluations at Low Nibthwaite and Greenholme are applicable to a wide range of sites. This will be necessary to enable a standard methodology to be recommended at the end of the project. Similarly, should the earlier evaluation work raise any areas of uncertainty, or circumstances dictate that it is not possible to carry out all the planned work (for example, a dry winter) then this work will also need to be completed at the remaining four sites.

(2) A comparison of gauge performance set up with and without the use of an oscilloscope to try and evaluate if this is essential or merely preferable.

(3) Evaluating the ability of the gauge to perform at compound structures. For example, can the transducers be mounted across the whole channel width u/s of a structure or, in the case of a compound crump weir, do they need to be used within each of the three sections and what benefits/disadvantages result from this? Ideally, one would seek to locate the gauge u/s of the weir in a natural channel but this may not be possible due to cabling/access/channel problems.

(4) One of the project's specific objectives is to evaluate the performance of the gauges at non-standard control structures, such as mill weirs. Clearly there will need to be at least one site with such a structure and, given the wide variety of such structures,

this may well become two or more. One specific problem that has already been identified is using the gauges u/s of a high weir which results in a deep pool of very slow moving water. Whilst we accept that it will not be possible to select four sites with all the criteria we would ideally seek, we would hope that one of the sites has a weir of this type.

(5) Another specific project objective is to evaluate the gauges under non-modular conditions. Whilst this will hopefully be carried out during the first winter, it would be beneficial to continue the evaluation into the second winter. Severn-Trent Region have already indicated that they have a number of standard structures at which flow becomes non-modular at high stages, and which have a cableway u/s of the weir. If other conditions are suitable, such as security and access, we plan to use one of these stations during this phase of the project.

During the post-tender communications we offered a number of items that we felt would be useful additions to the project. Whilst they are not all concerned with the actual gauge performance, they do all fall within the overall project objectives. We feel that the options are of sufficient importance that we have already altered the existing planned methodology to include a superficial assessment of two of them. However, if the issues are to be completely resolved then further work will almost certainly need to be carried out during the second winter season. The May and August Interim/Quarterly reports will allow a more complete evaluation to be made, but we feel it would be useful to outline the three options at this stage. They are as follows:

(1) An evaluation of the effects of suspended sediment loads on gauge performance. Whilst we plan to start looking at this at Greenholme we consider that it is important to assess the effects at different locations in catchments with differing land use, topography and geology. We estimate that this would cost a further £700 per site, depending on the number of sites used and the extent of study required.

(2) As previously mentioned, we plan to evaluate the potential of using the gauge on a reflector system at Low Nibthwaite during the summer season. If the results from this are satisfactory, we suggest that it would be useful to use at least one of the second winter sites in this way, most likely one where the transducers are to be installed during the summer. Our estimated fee for the additional fabrication and installation work is £1,600 per site.

(3) Finally, we note with some concern that the power supply and charger for each gauge cost more than 25% of the cost of the gauge itself. We feel that if the gauges are to become as cost effective as possible it would be prudent to assess the results of

using alternative, cheaper batteries. We thus suggest that alternative battery/charger configurations are evaluated, at a cost of £2,400.

We have already located a number of potential sites for the second winter within the North-West Region, and many more exist within their Southern Area. Similarly, both Severn-Trent and Northumbria & Yorkshire have offered the use of sites within their Region, whilst Anglian Region have even offered the use of a 1408 gauge already installed at a site. It would thus appear that rather than having difficulty in locating potential sites, we shall have to address the potential problem of selecting only four sites from what would appear to be a much larger list of suitable sites. Depending on the results of the first winter season, we may decide that it is both possible and beneficial to use more than four sites for the second winter season. This would solve some of the problems already identified regarding site selection, and may allow additional issues such as flows affected by backing-up to be looked at. Again, we would suggest that this is decided after the May Report.

The Interim Report submitted by 30 November 1996 will describe the early results of the second winter season, whilst the Quarterly Report to be submitted by 28 February 1997 will give the full results from the gauges operating at sites 3 and 4, along with their Site Reports. The results from the final two sites will be contained in the Summary Report to be submitted by 31 May 1997.

4.4 Project Completion

It is envisaged that the field work will be completed by May 1997 and, if required, we shall decommission the gauges ready for handing over to the Authority. Alternatively, the Authority may wish to leave the gauges in situ so that they can be used straight away.

The data analysis will be completed during May 1997, including an evaluation of the realistic costs and benefits of using the gauges in a normal hydrometric manner rather than as part of an R&D project. The draft Project Record and R&D Note will be completed for submission by 31 May 1997.

Once the Authority have passed back any comments on the draft documents, the final versions will be completed by 31st July. In addition to this, a presentation will be made to the National Hydrometric Group summarising the results of the project, and the gauges shall be formally handed over to the Authority.

PROGRESS REPORT 2 (28/02/96)

1 INTRODUCTION

This Progress Report details the progress made on R&D Project B01 (95) 01, Calibration of Gauging Stations Using Portable Ultrasonics, between November 1995 and February 1996. It has been written primarily to keep the NRA aware of the progress that has been made during the early stages of the first winter season and, whilst some initial results are presented in the report, no detailed analysis is included as this will form part of the Interim Report to be written in May 1996.

The project itself is evaluating the use of twin path ultrasonic time of flight instruments in a portable context to measure high flows at non-standard control structures, especially during non-modular conditions. Two gauges are being used for the project, and it is intended to use these at two sites for the 1995-1996 winter and at a further four sites during the 1996-1997 winter. The 1995-1996 sites are within the North West Region; it is intended to use sites within Severn-Trent and Northumbria & Yorkshire Regions for part of the second winter season.

2 LIAISON WITH THE NRA

Following the Project Inception Meeting a Scoping Report was written by SWS for discussion at the Progress Meeting held in Warrington on 11 December. The Scoping report was accepted, and the Authority requested that SWS provide a detailed work programme once the site details had been confirmed. This was submitted at the end of January 1996. It was agreed to use Low Nibthwaite (Crake) and Greenholme (Irthing) as the sites for the first winter season, and the contractor and Authority had a site meeting to discuss the objectives for each site.

The Authority offered to provide SWS with alarms from both gauging stations for the duration of the field work. This offer was accepted and the alarm system initiated, presently operating by word of mouth over the telephone network. To date the system has worked well with alarms being issued (and received) for the two events that occurred during February 1996.

Part of the project is concerned with using existing multi-path gauges to provide data that will allow the optimum configuration of two paths to be explored. All NRA Regions have agreed to help with this, and SWS have sent letters requesting that the data be collected. A similar request for reports/data from previous evaluations has been fruitless, and as a result the literature review is concentrating on external sources.

3 EQUIPMENT INSTALLATION

3.1 General

The equipment was delivered to SWS on 19 December 1995. Fabrication of the mounting systems was already underway and was completed by the end of December. Considerable time was spent at the two sites determining the optimum location for the transducer systems, particularly Greenholme where the presence of bedrock ledges in the main river channel caused problems. Despite the very cold weather (the River Irthing was actually frozen whilst installation work was being carried out) preparations at both sites were completed by Friday 5 January 1996.

It was decided to try and install the gauges, complete with ancillaries, during one day at each site with the assistance of the Peek technician. Thus, only the mounting racks were installed as part of the site preparation work, along with the cross-river cables at Greenholme to take advantage of the dry conditions. At both sites it was decided to bring the cables from the far bank transducers to the station via an aerial route. A 4 mm galvanised wire rope was used to support the cables, and this was stretched from the far bank gauging cableway tower to an anchorage on the station itself. An extension piece was mounted at the top of the tower to ensure that gauging operations are not affected. A description of the installation at both sites is given in Sections 3.2 and 3.3 below.

One early result from the installation work is that the gauges certainly satisfy the 'portable' criteria. Due to problems with a vehicle breakdown we had to use a hired Ford Fiesta to transport the gauges during the installation work. Both gauges, along with all ancillaries, mounting systems and equipment needed for the installation could be carried in the rear of this, and it is possible for one person to lift all components, though the power supply did cause some problems (see later).

3.2 Greenholme

The Greenholme gauge was installed on Tuesday 9 January 1996 by one technician from both Peek and SWS. Assistance was given by the Authority in transporting the equipment across the fields in a Landrover, and work commenced on site at 0900. By 1300 all equipment had been installed and cables connected; the power supply was connected and all transducers were tested. Due to problems with EPROM installation by Peek (with the gauges using a Psion to log the data the EPROM specification had altered) it took almost two hours to commission the gauge, though this problem did not recur at Low Nibthwaite.

One of the objectives of the installation with the Peek technician was to evaluate the need for an oscilloscope. At Greenholme it was found that the initial 'line of sight' alignment could not be improved by the ‘scope.

The installation was completed by 1600, with all work being carried out under daylight conditions. A breakdown of total time spent on site for the preparation and installation work is as follows:

Initial site survey	6 man hours
Site preparation	12 man hours
Installation/commissioning	14 man hours
TOTAL	32 man hours

In addition to this a further three hours have been spent conduiting the cables and mounting the gauge within the station.

3.3 Low Nibthwaite

The installation at Low Nibthwaite was carried out on 10 January 1996. Work again started on site at 0900, with the Peek technician leaving at 1600. The SWS technician remained on site until 1800 to tidy up the cables.

Whilst the Greenholme site is using the gauge with only four transducers operating in-line as two paths, it was decided as part of the Scoping Study to operate eight transducers at Low Nibthwaite with four paths in a cross-path configuration at two levels. It is hoped that by doing this it will be possible to evaluate the benefits (if any) of cross-path configuration, as-well as using both the 1 MHz and 500 kHz transducers.

Because of the additional set of transducers it could not be guaranteed that all paths would be commissioned during the single day. Efforts were thus initially concentrated on the 500 kHz transducers, which were successfully commissioned by 1200. The additional set of transducers were commissioned by 1430, with all 'technical' matters being completed by 1600. However, unlike Greenholme, it was not possible to merely line up the transducers by sight and the oscilloscope was needed to fully align the paths. Considerable difficulty was experienced in setting up the depth transducer due to electrical interference and Peek recommended that it was reinstalled at a later date, either as a tube gauge in the river or in the station stilling well.

The breakdown of time spent at Low Nibthwaite is as follows:

Site survey	6 man hours
Site preparation	16 man hours
Installation/commissioning	16 man hours
TOTAL	38 man hours

A further six hours have been spent trying to sort out the problems of the depth transducer at this site, and more will need to be spent as the performance is still variable.

It can thus be seen that whilst almost twice the amount of equipment was installed at Low Nibthwaite the time taken does not reflect this. Whilst this is partly due to the size of channel at both sites (the Irthing is almost three times as wide as the Crake) we feel it also suggests that time can be reduced the more familiar one is with the equipment. This will be explored further at the four sites used in the second winter season.

4 POWER SUPPLY AND DATA LOGGERS

4.1 Power Supply

One of the objectives of the first season was to confirm that the gauges are able to operate for the specified period (seven days) from a 12-volt power supply. Peek recommended that 115 Amp Hour Gel Cells were used to power the gauges and confirmed that they would meet the specification. Consequently, four cells were purchased with the gauges for use on the project.

Initial results confirm that the gauges are able to operate for the specified period from a single 12-volt cell, but only just. The Greenholme gauge was left for an eight day period during dry weather; when it was next visited the gauge had stopped and a significant part of the programmed data had been lost or, even worse, corrupted. Because of this it became necessary to visit the sites on a six-daily cycle merely to change the batteries.

In addition to this, two other issues caused concern with the power supply. The first was one of portability - the cells weigh almost 45 kg and are very awkward to manhandle across rough terrain. The second is that whilst the single cells might satisfy the seven day requirement they only do this through deep discharging which will shorten their lifespan. With the benefit of hindsight we would suggest that two 85 AH cells are used instead of the single 115 AH cell in the future; this will make handling much simpler and safer, lengthen the time between visits and prolong the life of the cells.

Having recognised these problems SWS asked the NRA to consider purchasing additional cells and a further battery charger. The Authority agreed to this and two further 115 AH cells have been purchased, along with another trickle charger. The present configuration is that Low Nibthwaite is powered by two cells which are kept in a fully charged condition by a trickle charge from the mains supply in the station. Should the mains supply fail the gauge will continue to work for a further two week period from the batteries. The Greenholme gauge is operating from two cells, and is visited at intervals not exceeding 12 days. The remaining two cells are recharged and then used to replace the Greenholme cells as necessary. This means that it is now possible to timetable station visits according to flow conditions rather than battery state, clearly of benefit to the project. The Authority have also agreed to consider the purchase of an additional two cells for the second winter season if needed, though this will depend on the sites chosen.

4.2 Data Loggers

Whilst it is not a specific objective of the project to evaluate that data loggers we feel that it is useful to report on their performance to date. Psion IIs are being used to log depth and one-minute values of velocity and discharge every 15 minutes from the gauge. The software is based on that originally written by the Thames Region of the NRA.

At the start of the project we voiced our concerns about battery life for the Psions to both Peek and Psion; both informed us that the units would operate for up to a week. We found that in reality the units will only operate for approximately 17 hours from a single cell, and lost some of the very early data (all low flow) from the Greenholme gauge as a result of this. After considerable effort we have managed to adapt the mains power inlet to enable the Psion to operate from the same 12-volt supply as the gauge itself. The additional drawdown is negligible, and we have found that the Psion will operate from a supply as low as 10 volts, ensuring that data will always be retained. Having sorted out the power supply, the Psion at

Greenholme has performed without fault. The unit would appear to be able to store more than two months' data on a single 256k flashpak, and this can be downloaded in a matter of minutes. One problem has occurred at Low Nibthwaite, due to a formatting error, but this only resulted in a two day data loss.

5 GAUGE PERFORMANCE

5.1 Greenholme

To date the gauge at Greenholme has given no problems other than those associated with the power supply and data logger described above. The gauge has worked continually since being recommissioned following the power failure, and data have been collected from two high flow events during February. Following the first event the upper transducer was raised by 100 mm, as stated in the work programme, whilst retaining the lower transducer at the same level. Whilst no detailed data analysis has been carried out yet, Figures 5.1 and 5.2 show the stage-velocity relationships for the two events. The data give a near perfect linear relationship, and the two relationships for the lower path differ by less than 2% suggesting that it may be possible to derive general relationships for each level. The lower path will remain at the same level for the next two events to evaluate this further, whilst the upper path will be set at different levels. Data have been collected from three different levels, and the transducers are presently deployed at the fourth awaiting the next event.

The depth measurement at Greenholme has always been within 2 mm of that recorded by the TG1150 in the gauging station, allowing the data analysis to be carried out with raw gauge data rather than having to rely on a secondary source.

One problem that has been experienced at Greenholme has been loss of data during the very top of the peak. This has been most noticeable for the lower path, and was especially bad during the first event. We suspect that this is due to high sediment loads within the river during the events - all transducers were cleared during the first event but counts remained very low. As the stage began to fall the lower path started to function once more, confirming that the alignment of the transducers had not been affected and that the missing data were not due to the transducers becoming obstructed. One of the options included with the Scoping Report was to look at suspended sediment loads and the early data suggest that this might be worthwhile.

Whilst the gauge has been calculating discharge on a continual basis we have not yet been able to compare this to that calculated from the stage-discharge relationship as we have yet to receive this (though we have received the data for Low Nibthwaite). We are in the process of requesting the supply of 15-minute Telegen data and will be asking for the relationship at the same time.

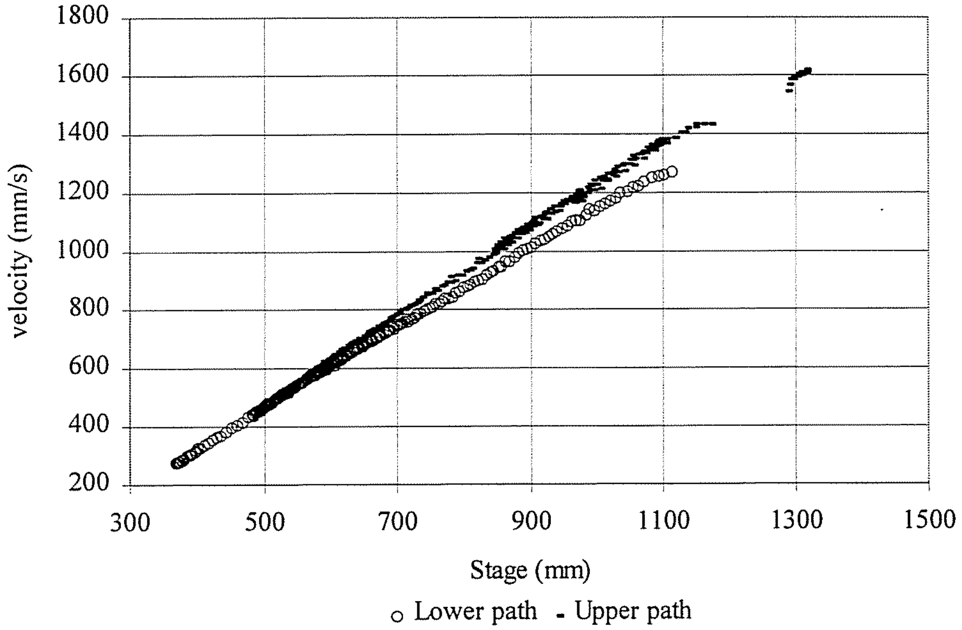

Figure 5.1 Stage velocity data collected from Greenholme between 10/2/96 and 15/2/96. The lower velocity path was at 0.088 m stage datum, and the upper at 0.388m.

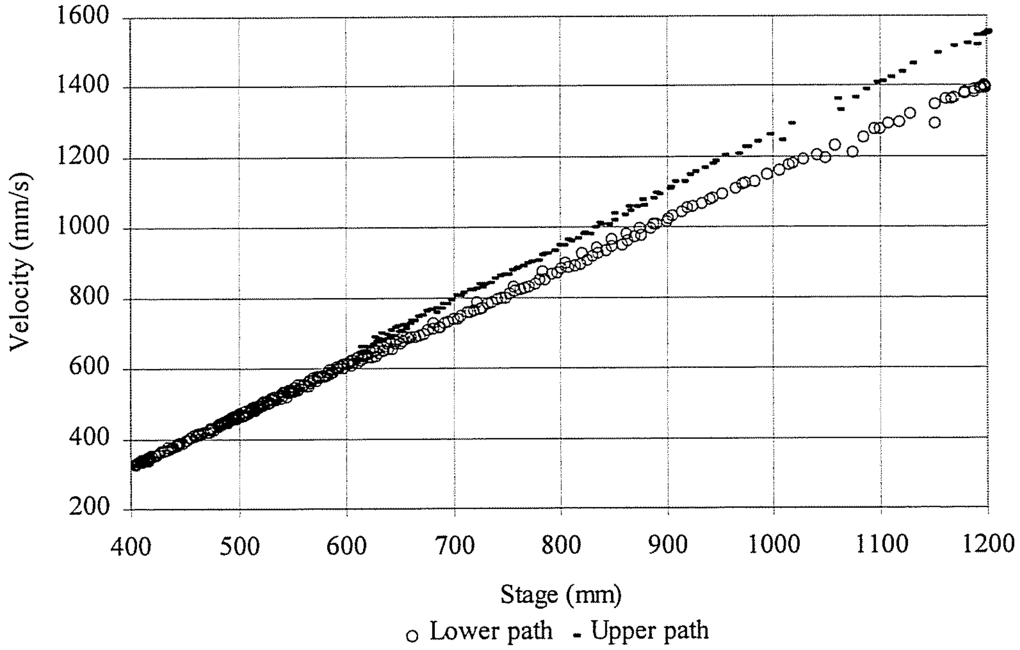

Figure 5.2 Stage velocity data collected from Greenholme between 17/2/96 and 21/2/96. The lower velocity path was at 0.088 m stage datum, and the upper at 0.488m.

5.2 Low Nibthwaite

Date returns from Low Nibthwaite have been rather less rewarding than those from Greenholme for a variety of reasons. Firstly, as previously mentioned, the gauge has at best been erratic in measuring depth and considerable time has been spent trying to resolve this. By reducing the gain on the instrument circuit board and increasing the voltage the signal has been improved, though it is still far from perfect and we may have to try and reconfigure the electrics with the use of an oscilloscope. Because of these problems it has not yet been possible to derive a stage-velocity relationship for any of the path levels, though we intend to do this once we get the Telegen data.

The second major problem that has occurred at Low Nibthwaite was not due to the gauge itself but was a result of very heavy snowfalls during January. These caused extensive damage to the fir tree which overhangs the gauging station and river section, and the broken boughs resulted in the transducer paths being blocked. The NRA kindly removed these at our request but, unfortunately, in doing so the alignment of the transducers was altered. We have subsequently managed to realign these without using a 'scope, and are now getting higher counts than before the disturbance!

One observation we would make from Low Nibthwaite is that whilst we had expected events to be attenuated, observations so far suggest that events are barely perceptible and so far have taken place over a matter of weeks rather than days. The transducer mounting system has allowed us to take advantage of this, facilitating the rapid alteration of path levels, and we may yet decide to alter our work programme at this site should no major events occur.

On a more positive note, the gauge has continued to collect velocity data from a total of five different paths at three different levels. It is possible to change from one set of transducers to another within a matter of minutes which gives a wide range of options for using the gauge in different configurations, and increases the flexibility of the equipment.

6 CONCLUSIONS

6.1 Progress to date

We feel that the project is progressing well, running to schedule without any major problems. The equipment has been successfully installed and commissioned, and has worked well given a suitable power supply. The installation and commissioning was completed in a single day at each site by two people, suggesting that the equipment does have potential for use in a portable context. Even when damaged it was possible to realign the transducers by line of sight, though it was necessary to use an oscilloscope at one of the sites to carry out the initial commissioning.

Whilst there have been problems with depth measurement at Low Nibthwaite this has not been the case at Greenholme, suggesting that it should be possible to resolve the problem given time. The lack of reliable depth measurement is not hindering the project at present as there is data available from the Telegen located in the station and the river is so slow to respond to any rainfall events. However, it is clearly important to try and determine the cause of the problem so that the same situation does not arise next winter.

Minimal data losses have been experienced at Greenholme during the peak of a high flow event. These data losses were greatest on the lower path although the higher path continued to function, suggesting that the problems were due to high suspended sediment loads. This is further confirmed by the observation that the lower path came back into operation as the stage fell. Whilst this has only been a minor problem, and was greatest during the first high flow event for almost three months, it does demonstrate one potential limitation of the equipment.

Whilst no detailed data analysis has been carried out, initial results confirm that the approach proposed in the work programme is both valid and viable. It has been possible to derive a clear stage-velocity relationship for different transducer path levels at Greenholme during a single event, and by keeping the lower path at a constant level for different events it has been demonstrated that the relationship is similar from event to event.

6.2 Potential Problems

The greatest single problem that the project faces is the lack of suitable high flow events in which to evaluate the equipment. There have only been three events at Greenholme during the winter, and one of these was before the equipment was even delivered, whilst only one alarm has been issued from Low Nibthwaite. None of these events were very high, and it is unlikely that non-modular conditions have been reached at either site. Whilst the gauges continue to collect data from any events that take place, there is a decreasing probability of very high flow events during the present winter season as we have, at best, only two months left.

Whilst this will present less problems at Greenholme where only one pair of paths is being used, it is of greater concern at Low Nibthwaite where two pairs are available. We are thus considering altering the present work programme to maximise potential data returns from this site by locating the paths at as many levels as possible whilst on site to provide 'snap-shots' of the different stage-velocity relationships. We shall keep the Authority informed of any decisions and progress made regarding this.

Whilst the present approach is producing useful data from Greenholme, we propose to increase the height which the transducer paths are raised from 100 mm to 200 mm after the next event to maximise the chances of collecting data from the higher path levels. Once (if) this is achieved, the transducers will be positioned at the intermediate levels to collect the data from the intermediate levels. When cleaning the transducers during one recent event it was possible to safely enter the water adjacent to the racks as they are positioned out of the main flow. It may thus be possible to collect data from different levels during a single event if necessary, as proposed for Low Nibthwaite.

PROGRESS REPORT 3 (28/6/96)

1 INTRODUCTION

This Progress Report details the progress made on the Environment Agency R & D Project W6/i646 (formerly NRA R & D Project B01 (95) 01), Calibration of Gauging Stations Using Portable Ultrasonics, between March and June 1996. Although the field monitoring is still continuing, it includes the site reports from both sites, along with the results of the data analysis carried out to date.

1.1 Liaison with the NRA/EA

To date the alarm system initiated by the NRA has worked well, with alarms being received for the event at the beginning of May 1996. Even though staff were working in the North West Highlands, some 400+ miles from the site, we were still able to get to the site whilst the event was taking place and ensure that useful data were recorded.

Richard Iredale of the Midlands Region of the EA has sent us some historic data from gauges operating on the River Severn, along with a copy of a report of investigations into the performance of an ultrasonic gauge at Bewdley on the River Severn. To date this is the only data we have received in response to our earlier request, although several Regions have contacted us to confirm that they have/will be collecting data. We are currently contacting the Regions once more to request that they send us any data they have collected so that we can commence the statistical analysis.

The provision of data from the North Area Office of the NW Region of the EA was initially very slow, with the observed data for January-March 1996 not being received until mid April. We understand that this was due to a review of the Stage-Discharge relationship being carried out at both stations, which was disappointing as one of the reasons the sites were initially selected was because we were told they had a stable Stage-Discharge relationship. This delay also meant that it took some time for a problem with the gauge at Low Nibthwaite to be identified, which had resulted in the loss of potentially useful data. The data for April and May 1996 was received in mid June, allowing the statistical analysis to continue.

Since April we have been receiving regular faxes of summary data from both sites, and we would like to thank Howard Waugh from the Carlisle office for his assistance in this. The data have been most useful in allowing us to assess the need for site visits and maximise the battery usage.

1.3 Literature Review

The literature review is proving to be much less straightforward than anticipated, mainly due to a lack of published information resulting in there being very little to review. We have carried out searches on a number of CD-ROM databases which deal with scientific research, especially in the physical geography/civil engineering/hydrology field. Initial results were promising, with a number of successful 'hits' being scored, but on obtaining full information on these 'hits' it was found that the databases had all located a special issue of one journal that was dedicated to flow measurement.

Because of this lack of published material in the journals we are having to focus on internal reports, or those published for a limited audience. We are presently awaiting information from the following groups:

Gauge manufacturers:

David Gibbard of Peek Measurement has had one paper on the use of ultrasonic gauges published (one of the 'hits' described above). Peek have advised us that, with this exception, they have no reports on gauge performance or assessment. We are currently trying to find out if they have any informal reports or site commissioning details that would allow us to try and determine an optimum configuration for the two paths.

OTT Hydrometry have sent us details of their AFFRA ultrasonic gauge, and have promised further information about the new DELTAFLEX gauge when it becomes available. This works on the interesting principle of using the surface of the water as a reflector to allow a vertically integrated velocity measurement to be taken. We may be involved with the installation of one of these gauges ourselves, in which case we shall, with OTT's approval, be able to report on its performance. OTT have sent a number of reports from Germany to their UK office, and they are presently trying to get them translated from German to English before forwarding them to us.

We are still awaiting information from Stork and Accusonic.

USGS

At the last Project Meeting in Warrington it was suggested that we contact staff at the USGS who have carried out studies on ultrasonic gauge performance. We are still awaiting information from this source, but believe that significant quantities may be available following a similar request we made for ADCP reports.

NRA/EA

Although all Regions of the Environment Agency replied that they have no reports on gauge performance, when questioned over the telephone a number of them admitted to having information stored away in a filing cabinet somewhere. Discussions between the Project Manager and Midlands personnel have resulted in the information described earlier being sent to us. We hope to be able to obtain more information of this type by making further telephone enquiries.

We have also been advised of work carried out by both the Midlands and North East Region of the Agency, though much of this is not published or recorded. As mentioned in a previous report, we hope to interview personnel at each of these Regions over the summer months to try and obtain as much assistance as possible.

Finally, although not strictly part of the literature review, we have received a positive response to our request that information be collected from ultrasonic gauges during high flow events. All Regions that operate gauges with RAR or RARII software agreed to collect data when possible. We are currently in the process of requesting that this information is sent to us to allow the analysis to continue.

2 SITE REPORTS

2.1 Greenholme

2.1.1 Gauge Installation

The Greenholme gauge was installed on Tuesday 9th January, and is still operating. Details of the gauge setup and configuration are given in Appendix A, which is an extract from the Peek Site Databook. The lower transducer rack was installed some 13 metres upstream of the weir crest, and the cables were routed from this to the station via the far cableway tower and then suspended from a 4 mm galvanised wire rope across the river. This method of getting the cables across the river has proven most successful, despite the presence of grazing cattle around the exposed cables on the far bank which meant that the cable had to be conduited part way through the spring. This was done by splitting some 32 mm alkathene water pipe lengthways and sliding the cables in through the slot.

2.1.2 Work Completed At Site

In addition to site visits made to install and commission the gauge, visits with Environment Agency staff and additional visits to resolve specific problems such as conduiting the cable have been made, making a total of 23 visits to Greenholme. The majority of these (18) have involved battery changing, whilst only 4 have coincided with river levels above 0.5 metres stage datum or higher, due to the very dry nature of the last six months. Data have been collected from all 'high flow' events, although it must be noted that the highest flow recorded of 59.4 cumecs is considerably lower than the previous maximum of over 350 cumecs.

It has been possible to operate the ultrasonic paths at a total of six different levels over five different events. As previously agreed with the Agency we kept the lower path at the same level for the majority of the season to confirm a consistent relationship between stage and velocity, and the upper path was raised after each significant event. The levels at which data were recorded were 0.088, 0.188, 0.388, 0.488, 0.588 and 0.688 metres above stage datum. The gauge is presently configured with the lower path at 0.288 metres in the hope that we can collect further data from summer showers. Should we experience a more prolonged period of rain the upper path is optimistically set at 0.788 metres.

With the benefit of hindsight, and having completed the initial analysis of the data collected at the site, we would operate the gauges in a different order if we were able to repeat the monitoring period, starting once more in the middle of the winter period. We would start with the transducers at high and intermediate levels, say 1.2 and 0.6 metres above stage datum, and move them down after data have been collected from each level. We would also move the transducers by 200 rather than 100 mm at a time to ensure that a greater range of depths was covered. Were the monitoring to start in the late autumn, as it will in 1996, we would raise the transducers as the winter progresses but again at a coarser interval, hopefully coinciding the high transducer levels with the higher, midwinter flows.

It must be remembered that over a six month monitoring period we have only experienced five events, three of which rose to above 1 metre stage. Our earlier analysis of the charts collected at the station suggested that we were realistic to expect an event of this magnitude every 10-14 days during the January - April period, with lesser events continuing thereafter. We thus feel that the monitoring programme has been a success given the dearth of high flow events that have taken place.

2.1.3 Gauge Performance

The gauge has generally worked well at Greenholme, yielding useful data despite the dry winter and spring. However, a number of problems have arisen due to both the instrument and site/location. The previous Progress Report described problems associated with the power supply, affecting both the gauge and data logger. This has since affected the gauge on only one occasion, ironically spanning one high flow event, when an interruption to the power supply caused the Psion to stop logging the data.

Sediment has also caused problems with the gauge, in two ways. During high flow events, particularly after a prolonged dry period, suspended sediment loadings appear to be high in the river. The individual paths have stopped working on a number of occasions at, or close to, the peak and have resumed operation when the river is falling. Whilst it cannot be proven that sediment is the cause, it is thought to be the most likely as it is usually the lower path which fails first. There have been occasions when only the upper path failed, and this may be due to turbulence or aeration.

The second problem caused by sediment was due to the depth transducer becoming silted up during low flows. Fortunately, when this happens, the gauge automatically tries to fire both paths and so no velocity data were lost. The problem was quickly solved by raising and clearing the transducer; we shall try to ensure that, in future, the depth transducers are installed at least 50 mm above the river bed, and clear them more frequently.

The final problem experienced at Greenholme was due to a failure in one of the gauge components. This was first noticed during a routine site visit when neither transducer path was working. A total of four trips were made to try and resolve this problem, which was hindered by the fact that the river was too low to guarantee that the failure was not due to insufficient water cover. Alternative transducers were tried, and the transducers repeatedly realigned but to no avail. Eventually we managed to convince Peek that the problem was with the gauge itself and they despatched a spare transducer board. This was swapped with the old one (about 10 minutes work) and both paths restarted immediately. Peek have subsequently found that the failure was due to one of the resistors on the board having been incorrectly specified. It is working outside its specification when the gauge is running at 400 volts, and consequently failed. Peek have not known this to happen before, even when working at 600 volts, but have since upgraded the specification and have asked us to return the Low Nibthwaite board when the gauge is removed so that they can upgrade it.

On a more positive note, when the new transducer board was installed we decided to realign the transducer paths from scratch and reset the gauge configuration accordingly. We have, over the course of the project, developed an easy to use method of aligning the transducers on the racks using a pipe of the same external bore as the outside diameter of the transducers. This pipe is passed through the transducer block on the rack, allowing it to be used as a sight for aligning on the far bank rack. The task is made even more straightforward by sliding the transducer mounting plate to the top of the rack, and allows the whole operation to be carried out without having to get one's feet wet. Both paths were aligned in this way, and maximum counts were recorded on the first set of pulses. It is thought that the path alignment may be even better than that achieved using the oscilloscope with Peek as we have been able to operate the gauge with a lower gain (amplification) setting since the transducers were realigned, with no decrease in data return. If it is possible to minimise the voltage needed at a site where the channel is more narrow than at Greenholme, it should be possible to extend battery life and thus reduce the frequency of site visits.

Whilst adjusting the transducers during a high flow event at Greenholme it was noted that the gauge is less sensitive to path alignment in the vertical plane. This was found when raising the upstream transducers by an initial 200 mm, when it was found that maximum counts were still being recorded by the gauge. Due to the rapidly falling stage (the event was on 1/2 May 1996) it was only possible to raise the upper path by this amount before it was out of the water. However, the lower path was raised by a further 200 mm, giving a total vertical misalignment of 400 mm. Even at these settings the gauge was still giving maximum counts, and the velocities were between those of the upper and lower paths when operating in the horizontal plane. The recorded data are given overleaf in Table 2.1. Whilst this observation has not been explored further, due to a lack of events, it may be added to the next winter schedule. It might be possible to set up the lower path along a vertical diagonal and leave the upper path at a much higher elevation to pick up velocities at the peak of high flow events. This offers even greater benefits when the weighting applied to the lower path velocities by Peek in the gauge software is taken into account.

Another observation that was made about the gauge performance is concerned with depth measurement. The gauge computes the depth of the water above the transducer using the velocity of sound in water calculated by the horizontal velocity paths. When the paths are not working (ie out of the water or have failed) the gauge uses the default setting of 1450 ms^{-1}. This results in the depth measurement being less accurate - typically up to 10 mm out. Whilst this is not too significant as the river flow is not being calculated when the paths are not working, it does have potential repercussions when the transducer paths become in range again. If the gauge is under-recording by 10 mm it will delay the path being recommissioned, causing minor data losses. One is able to overcome this potential problem by setting the minimum cover required for the transducers to work 10 mm lower than that found to be necessary.

Whilst talking about minimum cover, it is perhaps useful to pass on our findings on this matter. During a routine site visit we noted that the upper transducers were just breaking the surface of the water. As the minimum depth from the centre of the transducer to the surface is, in theory, 0.213 m, the path had been decommissioned by the gauge. We reduced the minimum cover parameter on the gauge to recommission the path and found that it was still giving maximum counts. Whilst it must be remembered that this was carried out at low flow conditions, when the water surface was smooth it did demonstrate that when correctly aligned the minimum cover required is much less than the theoretical value. We have thus been operating the gauges with the minimum cover set at 50 mm.

<table>
<tr><th colspan="3">Initial transducer settings at 0.088 and 0.588 metres above stage datum</th></tr>
<tr><th>Stage</th><th>Upper Path Velocity</th><th>Lower Path Velocity</th></tr>
<tr><td>0.897</td><td>1.122</td><td>1.007</td></tr>
<tr><td colspan="3">Both transducers raised by 200 mm on upstream rack</td></tr>
<tr><td>0.894</td><td>1.133</td><td>1.025</td></tr>
<tr><td>0.893</td><td>1.133</td><td>1.030</td></tr>
<tr><td>0.891</td><td>1.131</td><td>1.027</td></tr>
<tr><td>0.890</td><td>1.119</td><td>1.027</td></tr>
<tr><td>0.887</td><td>1.117</td><td>1.024</td></tr>
<tr><td>0.885</td><td>1.130</td><td>1.023</td></tr>
<tr><td colspan="3">Lower transducer raised by 400 mm on upstream rack</td></tr>
<tr><td>0.882</td><td></td><td>1.035</td></tr>
<tr><td>0.883</td><td></td><td>1.031</td></tr>
<tr><td>0.882</td><td></td><td>1.031</td></tr>
<tr><td colspan="3">Transducers set to initial settings</td></tr>
<tr><td>0.873</td><td>1.081</td><td>0.978</td></tr>
<tr><td>0.874</td><td>1.085</td><td>0.984</td></tr>
<tr><td>0.873</td><td>1.080</td><td>0.982</td></tr>
</table>

Table 2.1 Data collected during the event of 1/2 May 1996 when the upstream transducers were raised 200 and then 400 mm above those on the downstream rack, before returning the transducers to their original levels. The data show that there may be scope for setting at least one of the paths up in this way.

2.2 Low Nibthwaite

2.2.1 Gauge Installation

The Low Nibthwaite gauge was installed on Wednesday 10th January 1996 and, as with Greenholme, is still operating. Details of the gauge setup and configuration are given in Appendix A, which includes an extract from the Peek Site Databook. A total of four transducer racks were installed, with two forming the mounting for a 500 kHz set of transducers whilst the other two had 1 MHz transducers on them. The gauge was thus configured in a cross-path arrangement, as shown in the Peek diagram. The downstream rack on the 500 kHz transducer path was some 6.3 metres upstream of the weir crest, whilst the downstream rack on the 1 MHz transducer was 3 metres upstream of the weir. As with Greenholme, the cables were routed across the river suspended from a 4 mm galvanised wire rope, stretched from a pole strapped to the far cableway tower to an anchorage on the station wall. Unlike Greenholme, where bottlescrews had to be used, it was possible to tension the cable using the station winch. Due to problems with the depth transducer it was mounted in a tube which was in turn attached to the Agency staff board.

In general the transducer racks have stood up well to the demands placed on them at Low Nibthwaite. One rack was actually hit by a large branch which fell off due to very heavy snowfall in February and, despite the branch being lodged in the rack for some days, it was not adversely affected. We have also observed canoeists using the racks as a convenient mooring point, again with no adverse effects. However, the downstream 1 MHz rack, which is the closest to the weir, was damaged during the later part of the monitoring period. It is thought that a holiday-maker staying in the cottages adjacent to the gauge used the rack as a convenient ladder to get out of the river, and subsequently bent the upper bracket. This was the only damage to any of the racks at either site during the monitoring period, but does suggest that if they are to be used at a more vandal prone site it will be necessary to replace the alloy angle with hollow square section.

2.2.2 Work Completed At Site

A total of 17 trips have been made to Low Nibthwaite, in addition to those made with Agency staff and one to re-bury some of the cables prior to the Easter weekend. As the gauge was powered by two cells which were, in turn, kept charged by a trickle charger operating from the station's electrical supply, it was not necessary to change the batteries during the monitoring period. Many trips were made to try and resolve the problems encountered with the depth transducer; the Peek technician had been unable to get this to function correctly and it was the source of much frustration over the monitoring period.

Without doubt the greatest problem experienced at Low Nibthwaite was the complete lack of any high flow events. Over the entire five month monitoring period the river levels ranged by only 509 mm, and from 1st March to the end of May the range was less than 300 mm. Whilst it is accepted that the station was chosen to maximise the chances of collecting data **during** an event due to its location immediately downstream of a large lake, the very dry nature of the winter ensured that virtually no events took place.

This problem was identified in the last Progress Report, where it was stated that because of this we would be concentrating on the 500 kHz paths. At that point it had already been demonstrated that the 1 MHz units were able to work as well as the 500 kHz transducers, and it was felt more beneficial to try and gather as much data from as wide a range of levels as possible. As with Greenholme, we made the mistake of collecting data from the lower paths before raising the transducers. Data were collected from the 0.104, 0.304, 0.404 and 0.504 levels on the 500 kHz paths, and the transducers are currently set at 0.204 and 0.504 metres above stage datum. Useful data were only collected from the 0.104 and 0.304 levels.

To date it has not been possible to try and set the gauges up on a reflected path configuration. It had initially been hoped that it would be possible to do this at Low Nibthwaite due to the near vertical channel walls and narrow width of the channel. However, we have gathered that the general consensus of opinion on reflected paths is that they often cause more problems than they solve. One potential solution might be to use the reflector developed by OTT Hydrometry for use with their AFFRA gauge. Rather than rely on a flat plane to reflect the signal off like a mirror, the OTT reflector if formed from the inside faces of an isosceles triangle and reflects the transducer path like a prism. It is machined from large diameter round bar which ensures that the reflector is self cleaning. The price for the OTT reflector is under £1,000, subject to currency fluctuations.

2.2.3 Gauge Performance

As mentioned above, the gauge has continued to give problems with depth measurement since it was first installed at the site. We have tried alternative transducers, in and out of a tube, and in the station stilling well. No combination has worked any better than any other, even with the voltage and gain (amplification) being altered. The problem may be caused by high background noise, possibly caused by the turbulent nature of the channel or the overhead powerline which is less than 50 metres upstream of the station.

However, whilst the depth measurement might be a symptom that the gauge was struggling to work well at Low Nibthwaite, the depth transducer itself may not have been the problem. It was possible to get the depth measurement to work correctly by reducing the gain (amplification) on the return signal; this ensured that the first significant peak the gauge detected was caused by the reflected signal from the water surface, and was not an amplified 'noise' wave. When the gain was reduced in this way, even with the transducers firing at 400 volts, the lack of signal amplification meant that the gauge failed on the two velocity paths. This suggests that the problems might not be due to the depth measurement but were caused by the velocity paths struggling to work at this site. As the Low Nibthwaite site is significantly more turbulent than Greenholme, and the upstream riffles/rapids might cause aeration in the water, this may be another potential cause. The Agency have found similar problems with another 1408 gauge at their Duddon Hall site which are also thought to be due to aeration.

We finally managed to solve the problem by increasing the voltage to 600 volts and reducing the gain to minimum levels. Whilst this was possible at Low Nibthwaite, where the batteries were kept fully charged by the mains power, this configuration would result in decreased battery life if the unit were to be powered solely from the batteries.

With the exception of the depth measurement there have been no other problems at the Low Nibthwaite site. The gauge has worked continuously for almost six months without failing, and when the configuration has been correct the velocity paths have worked well.

3 ANALYSIS OF RECORDED DATA

3.1 Selection Of Events

At Greenholme there were six events when the river rose above 0.8 metres stage datum during the study period. The lowest of these, in mid January, was not recorded due to the problems with the Psion logger power supply described in the last Progress Report. The remaining five events were thus chosen for analysis. Summary information about the five events is given below in Table 3.1.

Event	Start of event	End of event	Lower path level (m)	Upper path level (m)
1	0000 on 10/02/1996	0000 on 15/02/1996	0.088	0.388
2	0000 on 17/02/1996	0000 on 21/02/1996	0.088	0.488
3	0900 on 23/04/1996	1200 on 26/04/1996	0.088	0.588
4	2300 on 01/05/1996	2400 on 04/05/1996	0.088	0.588
5	0000 on 29/05/1996	2400 on 31/05/1996	0.188	0.688

Table 3.1 Details of timing and path configuration for the five events used for analysis from Greenholme.

The Low Nibthwaite data showed that only four events took place on the River Crake over the study period, and once again the first one in mid January was not recorded due to the problems described in the last Progress Report. Rather than try and identify specific events we have split the Low Nibthwaite dataset into five periods, with each period including moderate to high levels and different path configurations. Summary information about the five periods is given in Table 3.2.

Period	Start of event	End of event	Lower path level (m)	Upper path level (m)	Transducers used
1	0900 on 11/02/1996	1200 on 15/02/1996	0.104	0.304	500 kHz
2	1500 on 15/02/1996	1200 on 25/02/1996	0.104	0.304	1 MHz
3	1500 on 25/02/1996	1200 on 08/03/1996	0.104	0.404	500 kHz
4	0900 on 15/04/1996	0900 on 09/05/1996	0.104	0.504	500 kHz
5	0900 on 22/05/1996	0900 on 01/06/1996	0.104	0.504	500 kHz

Table 3.2 Details of timing and path configuration for the five events used for analysis from Low Nibthwaite.

To date our analysis has concentrated on the data collected from the Greenholme site as this is the only one where reasonable flows have been achieved. Initial analysis has been carried out for the Low Nibthwaite site but, as we feel it is of very limited merit, we intend to discuss further work with the Agency at the next Project Meeting before progressing any further.

3.2 Analysis Of The Greenholme Data

When carrying out the data analysis we have tried to bear in mind the practicalities of running a hydrometric network, along with the likely applications that the gauges might be used for. We consider the potential uses to fall into two distinct categories:

1. Using the gauges to establish a 'ball park' estimate of peak flow. Such a use might be the calibration of a hydraulic model. The time available to collect the data might be very limited, possibly including only one event, so it will be necessary to configure and use the gauge to ensure that reasonable estimates of flows are obtained in as short a length of time as possible.

2. The gauges might be used to establish a stage-discharge relationship for a gauging station, be it a new one or one that has not been previously gauged. The time available for this might be longer, say over a six or twelve month period, but the accuracy of the output will need to be higher to ensure that the additional time spent by the hydrometric staff will be of benefit.

3.2.1 Using The Gauge To Calibrate A Single Event

Figure 3.1 shows the flows recorded by the 1408 gauge for the first event plotted together with those recorded by the Environment Agency. The gauge flows are those recorded by the gauge using the default settings, and all physical parameters are as measured in the field. First impressions are that the gauge appears to perform well, particularly at the peak flow of 59 cumecs, but that it does overestimate during low and intermediate flows.

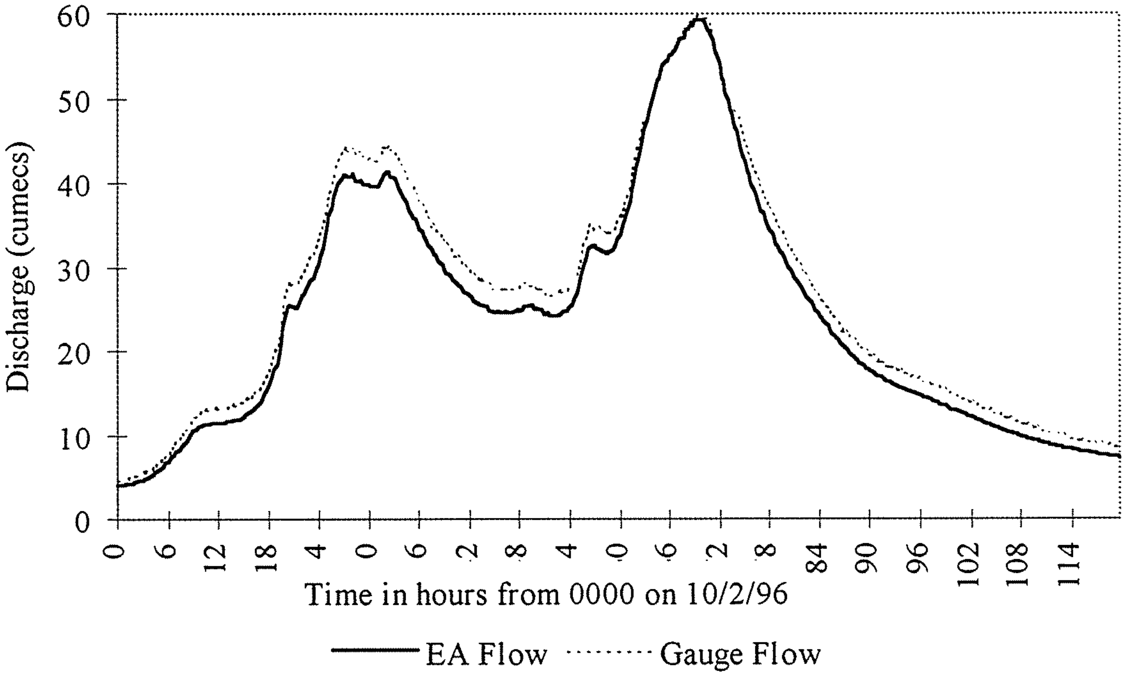

Figure 3.1 Recorded and gauge flows at Greenholme between 10/2/96 and 15/2/96

Rather than try to assess the gauge performance on a subjective visual impression it is more useful to look at its performance at determining the flows in an objective manner. As the gauges may be used to calibrate events within known confidence levels, the percentage difference between recorded and gauge flows for the event were calculated and plotted in Figure 3.2. From this it can be seen that, when compared to the values provided to us by the Agency, the gauge is over-predicting the flow by up to 18%, though this over-prediction falls to less than 1% at the peak. Given that the primary purpose of the project is to evaluate the potential for using the gauges at high flows this early result might appear most promising. However, close examination of the velocity data recorded by the gauge shows that, at the peak, only one of the paths was working. Had the second path been functioning the gauge would have produced larger errors at the peak flows than those shown in Figure 3.2.

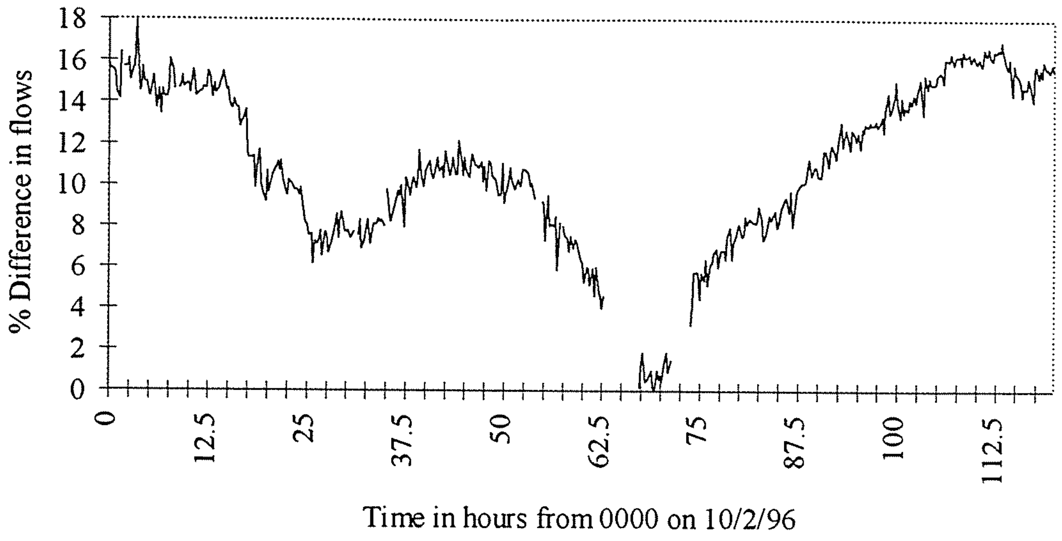

Figure 3.2 Percentage difference between gauge and recorded flows at Greenholme between 10/2/96 and 15/2/96

It can thus be seen that, using the default settings, the gauge overpredicts flows, and that this is most noticeable at low flows. Further examination of the data reveals that under such conditions only the lower path is working. If it is accepted that the gauge is measuring the velocity accurately, and we have been told by both Peek and the Agency to assume this, then it is clear that the gauge is not applying the measured path velocities to the panel of water it represents accurately. If the data are studied it can be seen that the channel bed is some depth below stage datum, particularly close to the near bank when it is almost 0.7 metres below stage zero. Given that the weir crest is just over 0.1 metre below stage datum, it can be seen that there may be some pooling of water upstream of the weir, particularly during low flows. Peek acknowledge that this is often the case, and advise that the mean bed level is adjusted to allow for this. At this point it is perhaps useful to explain the importance of this parameter in calculating the discharge using the gauge software.

The Peek gauge applies the velocity measured along the lower path to two panels, both of which exist across the whole river section. The velocities measured along the upper path are applied to only one panel. The panels are identified as follows:

1 The lowest panel extends from the mean bed level to the mid-point between this and the transducer path level. For example, if the mean bed level is 1 metre below stage datum, and the lower transducer path is at 0.2 metres above datum, the lowest panel

will extend from -1 metre to -0.4 metres. The gauge applies 0.8 of the measured path velocity to this panel.

2 The middle panel extends from the upper limit of the lower panel to the midpoint between the two transducer path levels. To continue the above example, if the upper transducer path is at 0.8 metres stage datum, the mid panel will extend from 0.4 metres below stage datum to 0.5 metres above it. The gauge applies the lower path velocity to this panel depth.

3 The upper panel extends from the upper limit of the middle panel to the water surface, and the velocity measured along the upper path is applied to this.

The mean bed level can thus be seen to be very important in the gauge calculations of discharge, particularly during low flows when it may be that only the lower path is covered and the lower two panels are the sole contributors to discharge.

Having identified the importance of the mean bed level parameter, we then had to decide how best to adjust this in a manner that might be replicated in the field when installing the gauge. Whilst the performance of the gauge could no doubt be improved by optimising this parameter over a whole event in this case, when the gauge is used to calibrate a single event at a site for which there is no rating equation it will not be possible to do this. We thus decided to set the bed level using only the first recorded flow value provided by the Agency for this event. We feel that is reasonable as it should be possible to obtain similar results in the field by carrying out a detailed gauging. The mean bed level was adjusted in this manner from -0.430 m to -0.32 m. We only took the adjustment to the second decimal place as we felt it was unreasonable to expect a gauging to be carried out to any greater accuracy. This adjustment resulted in the first flow value recorded by the gauge for event 1 reducing from 4.55 cumecs to 3.94, compared to the Agency value of 3.924 cumecs.

The data were then reprocessed using this revised mean bed level, and the resulting flows are plotted in Figure 3.3, along with the flows initially calculated by the gauge and those recorded by the Agency. From this the improvement in gauge performance can clearly be seen, though it must also be noted that the gauge now calculated the peak flow worse than it did before the bed level was adjusted. If it is remembered that the upper transducer path for this event was only at 0.388 metres, almost 1 metre below the peak water level, and that one of the velocity paths failed during the peak event, this underestimation can be both understood and explained.

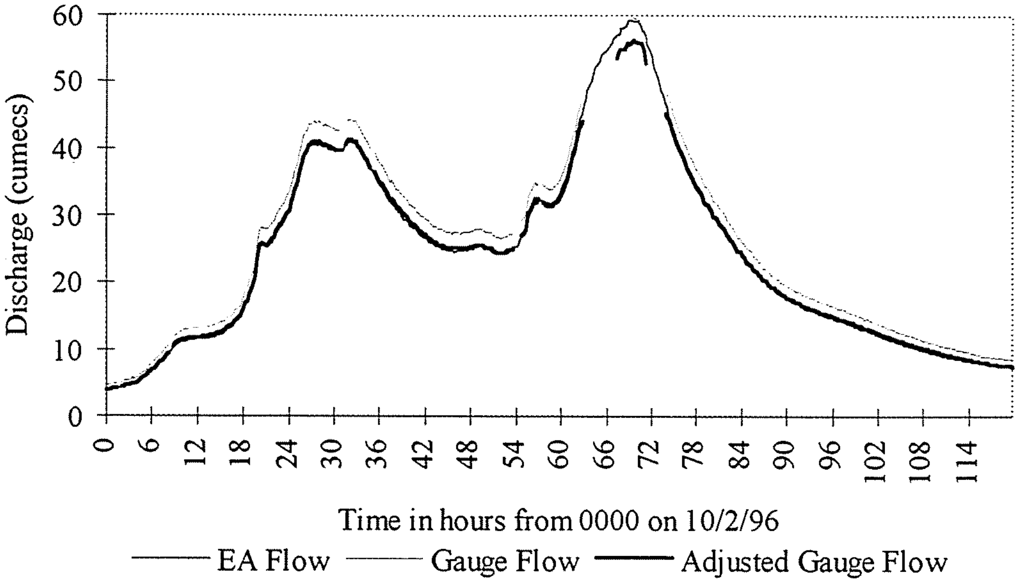

Figure 3.3 Recorded, gauge and adjusted flows at Greenholme between 10/2/96 and 15/2/96

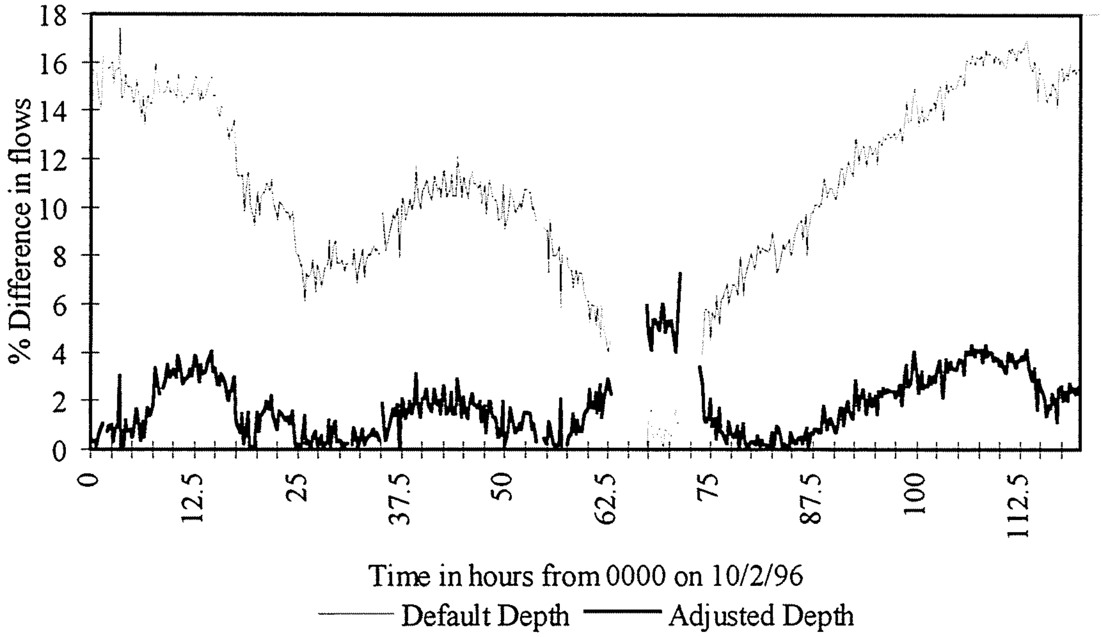

Figure 3.4 Percentage difference between gauge flows calculated with both default and adjusted mean bed levels, and recorded flows at Greenholme for event one

Figure 3.4 shows the percentage difference between adjusted and recorded flows compared to those when the gauge was using the default depth. The improvement in gauge performance can be clearly seen, with the maximum difference being just above 6% at the peak. The mean % difference for the adjusted gauge data is 1.45% compared to the previous mean of 8.07%.

The second event from Greenholme was processed in the same way. Initially the mean bed level was adjusted to the same value used for Event 1, ie -0.32 m. It was found that, due to the upper transducer path being some 100 mm higher, causing the middle section to which the lower path velocities are applied to increase by 50 mm, the level had to be raised 20 mm to -0.3 metres to match the first flow values for this event.

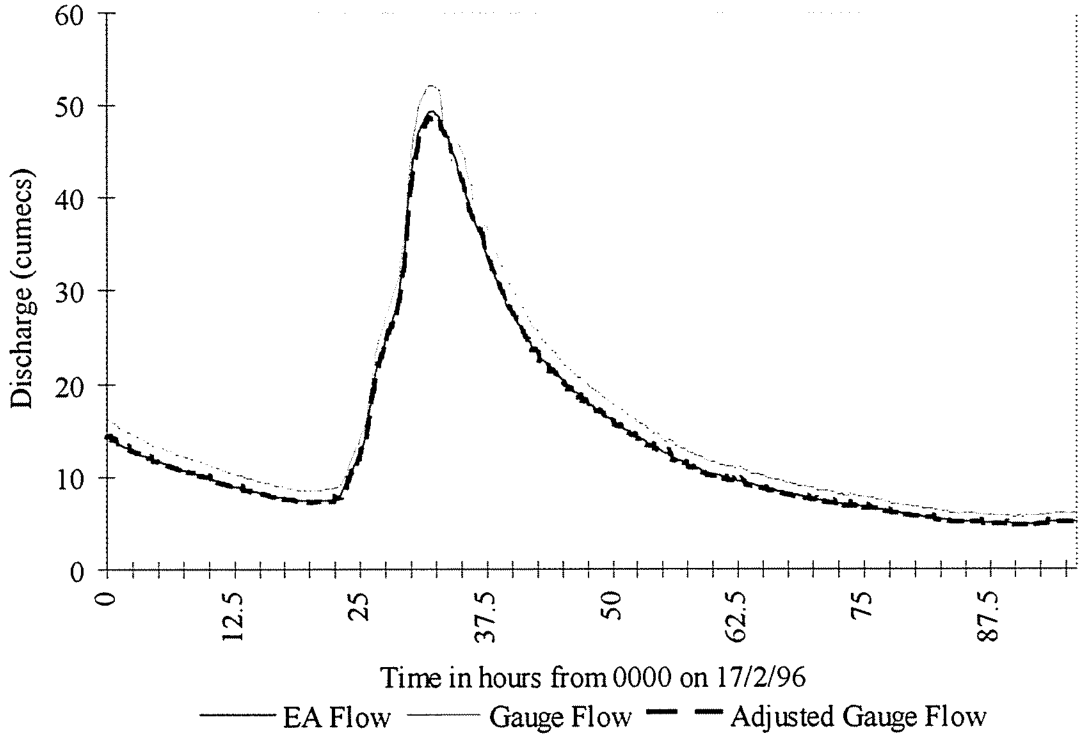

Figure 3.5 Recorded, gauged and adjusted flows at Greenholme between 17/2/96 and 21/2/96

On studying the plots of gauge and recorded flows, which are shown in Figure 3.5, it was noted that at two points on the recession, just after the peak, the gauge flows appeared to fall much quicker than those recorded by the Agency. The data revealed that this was due to the upper path failing for two periods, both of just over two hours duration. It was decided to fill in these missing values to see how much effect this had. Whilst it would be possible to interpolate between the two values either side of the missing series, we merely repeated the last value for the whole of the missing series. The resulting flows are also plotted on Figure 3.5, from which it can be seen that it is very difficult to separate the adjusted gauge flows and those recorded by the Agency. Figure 3.6 shows the % differences between recorded and gauged flows, using both default and adjusted mean bed levels. The improvement visible in the plot reflects a decrease in mean percentage difference from 13.31% to 0.76%.

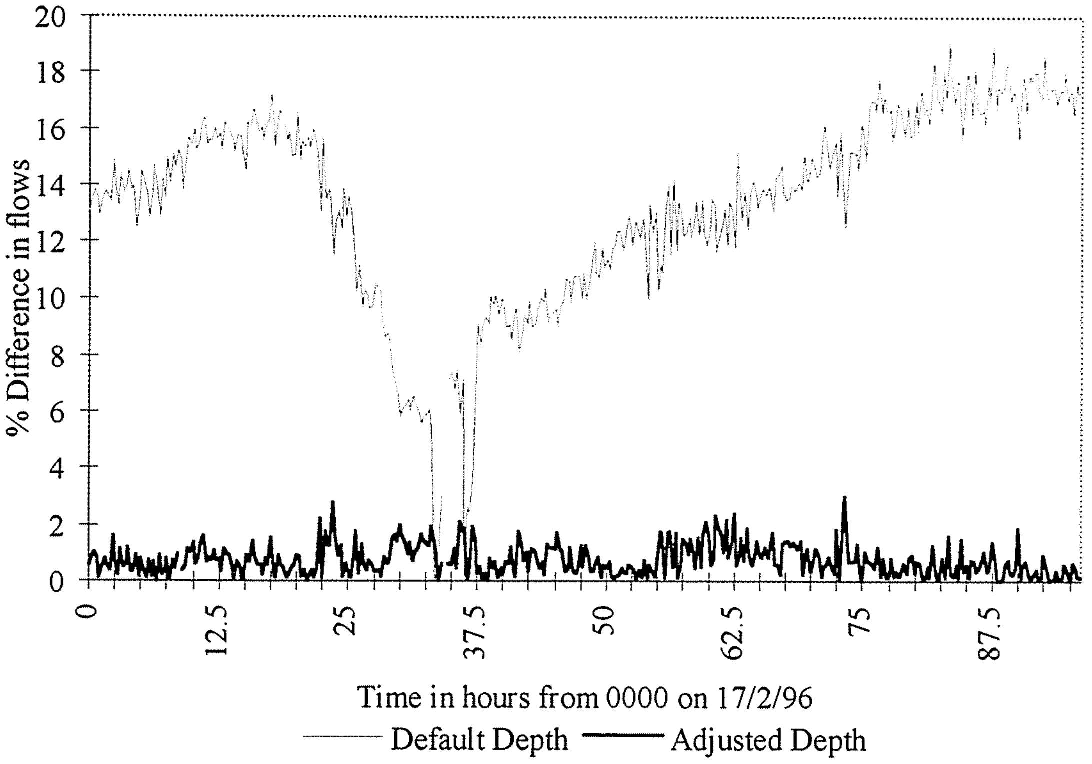

Figure 3.6 Percentage difference between gauge flows generated with both default and adjusted mean bed levels, and recorded flows at Greenholme for event 2

This analysis was repeated for the remaining three events, with missing data being filled in for part of Event 4. As these events are all of a much lower magnitude than Events 1 and 2 we have not included the time series plots in the Report. Summary results are given in Table 3.3.

	Event 1	Event 2	Event 3	Event 4	Event 5
Q Mean	24.64	14.14	11.44	8.07	9.54
Q Max	59.27	49.42	19.79	29.77	30.24
Height of low path	.088	.088	.088	.088	.188
Height of high path	.388	.488	.588	.588	.688
Default gauge bed level	8.07%	13.31%	5.05%	8.66%	5.75%
Initial adjusted bed level	1.45%	1.92%	6.04%	4.27%	4.23%
Event specific bed level		1.55%	1.05%	2.55%	1.09%
Event specific bed level and extended data series		1.39%		2.30%	

Table 3.3 Summary results of the analysis carried out on the data collected during the five high flow events at Greenholme over the period January - May 1996

From these data it can be seen that over all events the gauge performed well, and after adjusting the mean bed level based on a single known flow value the performance was improved even further. For all events the gauge performed to within 2.5% of the Environment Agency rating.

3.2.2 Using The Gauge To Derive A Stage Discharge Relationship

Multi-path ultrasonic gauges determine the channel discharge by splitting the channel cross section into many vertical panels, each with a transducer path running through the centre. At the start of the project we stated that we thought it would be possible to use the two paths of the 1408 to replicate this by operating the transducer paths at different levels for different events, and by using the collected data to derive **stage-velocity** relationships for each path level. These relationships could then be used to derive a stage-discharge relationship using the same principles as the multi-path gauges.

Having operated the Greenholme gauge at a total of six different path levels we determined a stage velocity relationship for each of these paths. As this was an exploratory exercise it was decided to derive the relationship using simple linear relationships, though it is realised that these may not be the most suitable method at higher stages. Six relationships were derived using this method, and they are given in Table 3.4.

Path Level	Best Fit Linear Regression Line	R^2 value
0.088	V = 1362.8 stage - 213.03	0.9986
0.188	V = 1465.6 stage - 265.2	0.9989
0.388	V = 1442 stage - 210.67	0.9958
0.488	V = 1532.2 stage - 275.97	0.9991
0.588	V = 1631.1 stage - 337.52	0.9851
0.688	V = 1755.5 stage - 265.2	0.9989

Table 3.4 Best fit lines derived for stage-velocity relationships for the transducer paths at Greenholme using the data collected between January and May 1996.

These relationships are plotted below in Figure 3.7.

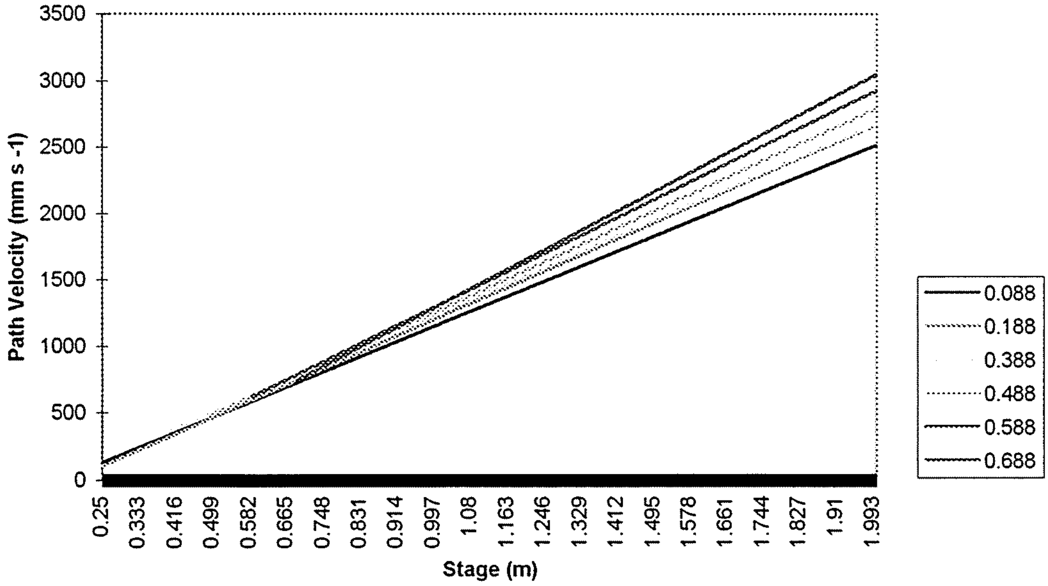

Figure 3.7 Stage velocity relationships derived for the six transducer path levels at Greenholme

These relationships were then used to derive a stage relationship for the channel section using the same method as the multi-path gauges. The resulting relationship is plotted overleaf in Figure 3.8, which also shows Rating 08 used by the Agency for the past twenty years, along with the rating that was approved for use in March 1996. Figure 3.9 shows the deviation of the gauge six-path derived relationship from these two ratings.

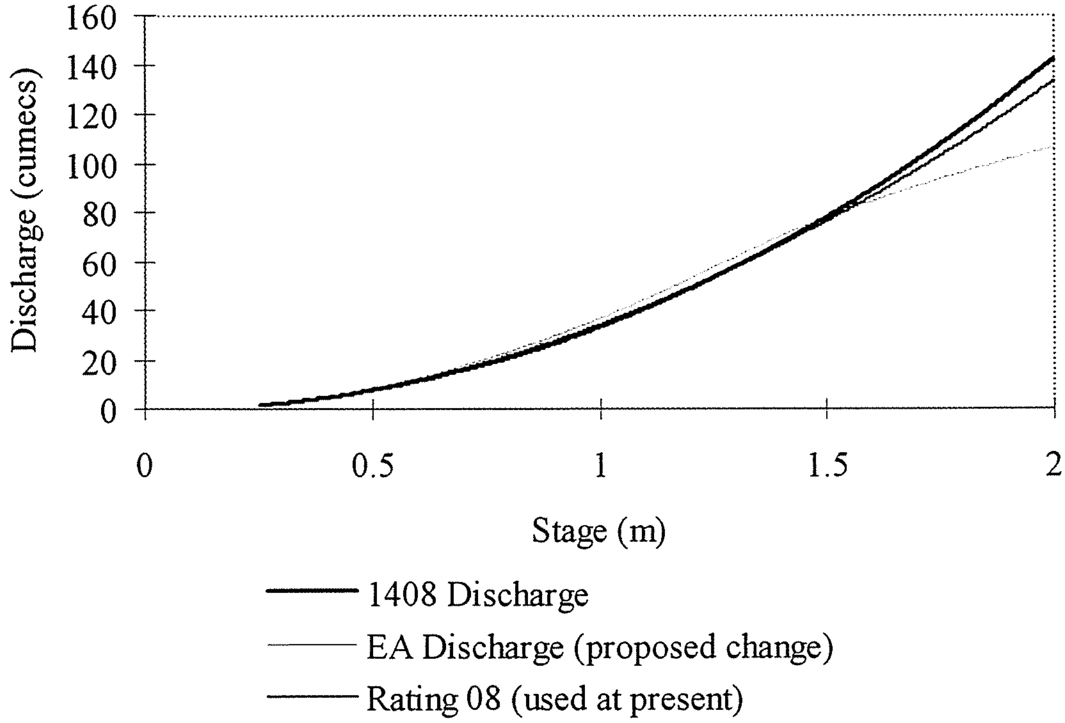

Figure 3.8 6-path derived stage discharge relationship compared to those used by the Environment Agency

From these it can be seen that the 6-path derived relationship performs especially well when compared to Rating No 08 which was used by the Agency for so long. It performs particularly well at stages up to 1.5 metres, never differing by more than 5%. Even at the two metre stage the deviation is less than 7% which is quite impressive if one remembers that the highest transducer path was only at 0.688 m.

However, the performance is less impressive when compared to the newly revised rating. Whilst it again performs well up to the 1.5 m level, above that it begins to depreciate significantly with the deviation being over 30% at the 2 m level. It must also be noted that Rating 08 also behaved in a similar way, clearly visible in Figure 3.8, and if the new Agency rating is extended to above three metres it becomes concave once more, eventually rising to meet the two upper curves.

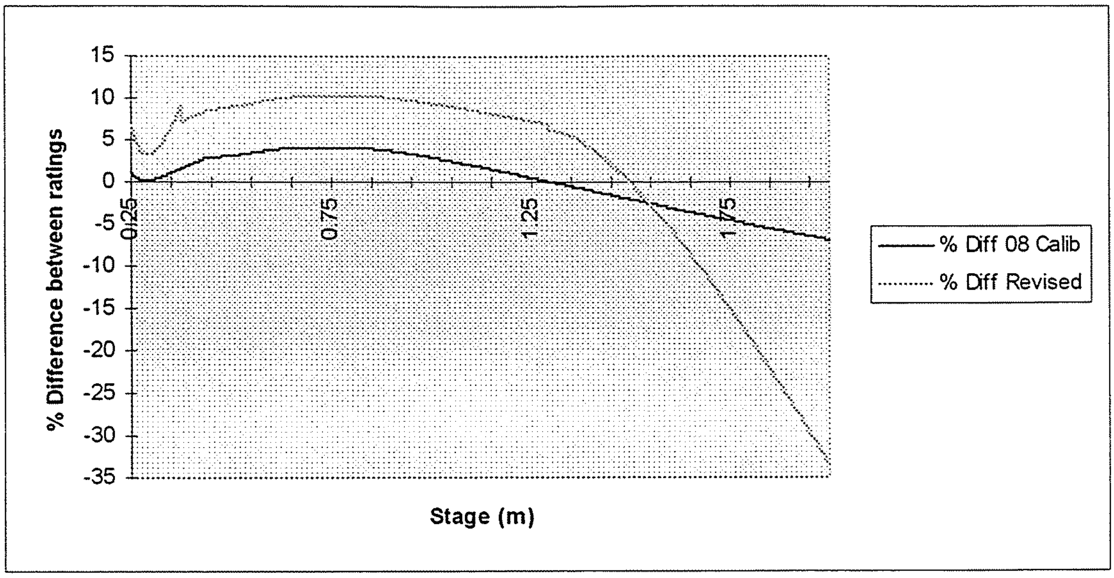

Figure 3.9 % Deviation between the stage discharge relationship derived by the gauge and those used by the Agency.

To try and put the derived relationship into some kind of perspective we looked for the highest recorded flow over the whole monitoring period, and compared the value calculated by the gauge derived relationship to that given to us by the Agency. The Agency peak flow of 59.269 cumecs compares most favourably to the gauge's derived value of 59.268 cumecs, a difference of less than 0.002%! It can thus be seen that when the relationship is applied to the same range of flows over which the data were collected it is able to perform very well. Further analysis, involving the use of non-linear best fit lines, may improve this performance even more. It is most encouraging to note that the gauge was able to perform within 5% of the rating used by the Agency since September 1975 after only five months' use.

3.3 Analysis of the Low Nibthwaite Data

As mentioned earlier, the analysis of data collected from Low Nibthwaite is very limited as we feel it is of little potential benefit given the low flows that were recorded at the station over the monitoring period. The data have been sorted by event and we have started on developing the artificial stage-discharge relationship that will be compared to that used by the Agency. We intend to discuss this at the next Project Meeting before progressing any further. We have compared the flows recorded by the Agency to those calculated by the gauge, and for all five periods the gauge is able to perform well, regardless of transducer type or path configuration. Figure 3.10 below shows the recorded and gauge flows for Period 1 as an example.

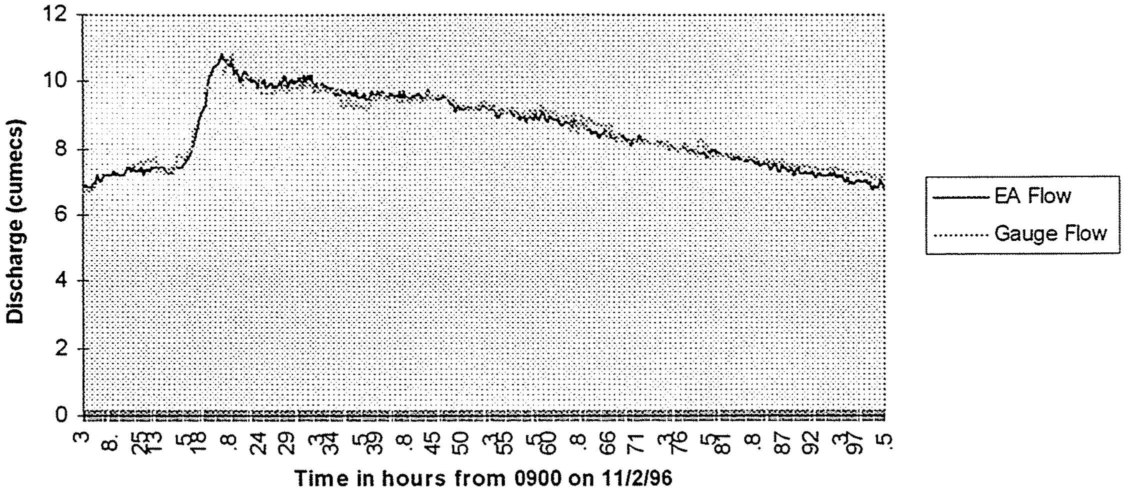

Figure 3.10 Recorded and gauged flows at Low Nibthwaite between 11/2/96 and 15/2/96

3.4 Summary Of Analysis

The analysis of the data carried out to date has been most encouraging. At both sites the gauges have been able to replicate the observed pattern in flows, and by adjusting the mean bed level it has been able to get the gauges to perform within 2.5% of the flows recorded by the Agency over a number of events. Rather than optimising the bed level parameter on a whole dataset it has been found that by using the first recorded flow value to represent a gauging the level can be determined to a more than satisfactory level. We are presently carrying out some sensitivity analysis on the importance of determining the mean bed level to within identifiable limits, which will then allow us to determine the required accuracy of the gauging to meet this target. At present it would appear that the gauges offer great potential for calibrating individual hydrological events.

The Greenholme data have also been used to generate stage velocity relationships for each of the levels at which the transducer paths were operated. Linear regression techniques were used to create six relationships, all with r^2 values greater than 0.99, and these relationships were then used to generate a stage discharge relationship. This relationship was found to be within 5% of the rating used by the Agency since 1975 over the measured range of flows, even though the upper transducer was still almost a metre below the surface. The derived relationship gave a flow within 0.002 % of that recorded by the Agency for the highest event of the monitoring period. At higher stages the curves diverge, with the difference being less than 7% at the 2 metre stage level.

The Agency have recently revised their rating curve, which is further from that produced by the gauge than their previous one, particularly at higher stages. Further work on the stage-velocity relationships, some of which are derived from less than 20 points, should improve the situation, possibly through the derivation of a family of stage-velocity relationships similar to those used in the Low Flow Studies Report.

4 FUTURE PROGRESS

As has already been identified, we plan to continue the data analysis over the summer months, including that of data collected by the Agency on our behalf. At the end of the summer we hope to have developed a methodology that can be tested over the 1996/1997 winter season.

At present we still plan to use four additional sites for the next winter. However, should it prove to be as dry as that of 1995/1996 we shall have to review the situation, possibly restricting our studies to only two or possibly three sites. We shall be discussing the site requirements with the Agency at the forthcoming Project Meeting before visiting the Midlands and North East Regions to try and identify possible sites, along with collecting information on their experiences with ultrasonic gauges for use in the literature review.

At present we would suggest that the next two sites are located within the North East and North West Regions, preferably as close to each other as possible whilst still ensuring that a reasonable catchment size is obtained. The second set of sites might then be located in the South Area of the North West Region, along with one in the northern part of the Midlands.

We stopped monitoring at Greenholme and Low Nibthwaite at the end of June, though the equipment is still in place. It might be advisable to remove both gauges before the school holidays commence to reduce the risk of vandalism, and to allow preparations to start for the next two sites.

PROGRESS REPORT 4 (16/11/96)

1 INTRODUCTION

This Progress Report details the progress made on the Environment Agency R & D Project W6/i646 (formerly NRA R & D Project B01 (95) 01), Calibration of Gauging Stations Using Portable Ultrasonics, between July and November 1996.

2 LIAISON WITH THE AGENCY

A Project Progress Meeting was held at Richard Fairclough House, Warrington, on Tuesday 9 July. Progress Report W6/i646/3 was discussed in detail, along with plans for future work on the Project. A brief resume of the progress to date was made at a National Hydrometric Group meeting at Malmesbury in August, and an informal meeting was also held on Friday 7 November to discuss site selection for the winter season.

Following the July Progress Meeting we contacted the Regional offices to chase up any data that had been collected on our behalf during the previous winter from existing gauges. Due to the very dry nature of the winter it emerged that only the North West Region had managed to collect any RAR data during an event. We are currently contacting the Regions that had agreed to collect data on our behalf to request that they collect data during any events that may arise between now and February 1997.

Considerable time was spent at the Progress Meeting discussing different options for site selection, and it was decided to try and use sites located in the North East, Midlands and Welsh Regions if possible. These Regions were contacted to suggest potential sites, and we visited more than twenty sites that were thought to be suitable. Following this initial viewing, we have had site meetings with Agency personnel from all three Regions at a number of stations that we felt could be used for the Project.

Once the first two sites had been selected for the season we requested further information from both the Midlands and Welsh Regions, and these requests have been dealt with in a most efficient manner. Both Regions have been particularly helpful over the past month or so, and continue to supply all requested data as quickly as possible.

3 LITERATURE REVIEW

The work on the literature review has continued, with some progress being made. We have managed to secure both reports and technical information from Accusonic for inclusion in the review, and have managed to trace a supplier of possible information from Canada at a seminar on the OTT Deltaflex/AFFRA system held by Hydrodata at the NEC. Our efforts to secure information from the USGS have, to date, proved fruitless although we are about to try contacting them through the world wide web. We have managed to secure no further information from the Agency, other than that supplied by the Midlands Region.

4 ANALYSIS OF THE GREENHOLME DATA

At the Project Progress Meeting held in July considerable time was spent discussing the merits of altering the bed level during low flow events to fine tune the gauge, as recommended by Peek, or adjusting the correction factor used to reduce the velocity in the lowest panel. It was decided to explore this further using the data collected at Greenholme.

The same five events that were used for the work detailed in Progress Report W6/i643/3 were used for this analysis. A simple model was created and operated as follows:

1. The optimum bed level was set using only the first four observations recorded by the gauge once the river had started to rise, representing data collected during the first hour of an event, with the reduction factor being set to the Peek default value of 0.8. This bed level was then used to calculate the flow for the whole event. The optimum level was identified by minimising the difference between observed and calculated flows, both in absolute and % terms. For methods three and four these often produced slightly different results (due to positive and negative differences) in which case the % difference factor was used;
2. The reduction factor used to apply the velocity recorded over the lowest path to the lowest panel was optimised using the same method, on the first four observations. The bed level was set to that measured during the initial channel survey;
3. The bed level was then optimised using data collected over the whole event, ie with the benefit of hindsight;
4. Similarly, the reduction factor was optimised using the complete data set.

The results of this analysis are summarised below in Tables 4.1 to 4.4:

Table 4.1 Summary results obtained from optimising the bed level using only the first four observations

Event	Bed Level	Mean difference in flows (cumecs)	Mean % difference in flows
1	-0.32	0.401	1.84
2	-0.29	0.198	1.40
3	-0.33	0.597	5.06
4	-0.39	0.202	4.19
5	-0.36	0.247	2.20
Mean		0.329	2.938

Table 4.2 Summary results obtained from optimising the reduction factor using only the first four observations

Event	Reduction factor	Mean difference in flows (cumecs)	Mean % difference in flows
1	0.41	0.900	3.19
2	0.32	0.184	1.24
3	0.46	0.572	4.85
4	0.65	0.186	3.87
5	0.60	0.235	2.06
Mean		0.415	3.042

Table 4.3 Summary results obtained from optimising the bed level using data collected during the whole event

Event	Bed Level	Mean difference in flows (cumecs)	Mean % difference in flows
1	-0.30	0.395	1.33
2	-0.30	0.116	0.750
3	-0.38	0.106	1.05
4	-0.36	0.169	2.29
5	-0.38	0.131	1.67
Mean		0.171	1.30

Table 4.4 Summary results obtained from optimising the reduction factor using data collected during the whole event

Event	Reduction Factor	Mean difference in flows (cumecs)	Mean % difference in flows
1	0.44	0.799	0.316
2	0.36	0.115	0.732
3	0.63	0.105	1.06
4	0.57	0.166	2.36
5	0.65	0.117	1.05
Mean	0.53	0.259	1.68

From these data it can be seen that there is little to choose from either method, and that both methods would appear to give an acceptable performance, the mean average percentage difference between observed and calculated flows being no more than 3.05% by any method, and less than 5.1% for any individual event. It would appear that adjusting the bed level gives marginally better results when the methods are compared over the five events as a whole, but it must be noted that this approach also gives the highest errors for single events. Additional observations are that the mean bed levels appear to fall within a narrower range than the reduction factors, and that all the reduction factors are significantly less than the 0.8 value used by Peek in their software.

Whilst these results demonstrate that the gauge can produce acceptable results when operated in a number of different ways, it is important to remember that if a general, simple approach can be established that does away with the need for calibration or optimisation of specific parameters, this will significantly help the Agency in using the equipment at a wide variety of sites with different personnel as it will allow a consistent procedure to be followed. With this in mind the model was re-run for the five different events, using the mean bed level or reduction factor as appropriate. The results from this are given overleaf in Table 4.5.

From these results it can again be seen that adjusting the mean bed level would appear to be the better of the two approaches, particularly as the average of the five mean bed levels is the same for both methods 1 and 3. It can also be seen that using the mean bed level obtained from only the first hour's data for each event gives marginally better results than setting the reduction factor from the complete data sets for all events.

Table 4.5 **Summary results obtained by using the average mean bed levels and reduction factors from the four different methods and applying them to the five individual events.**

Method 1, mean bed level -0.34	Event1	Event2	Event3	Event4	Event5	Mean
Mean difference in flows	0.621	0.439	0.487	0.267	0.436	0.450
Mean % difference in flows	3.27	3.94	4.11	2.87	4.36	3.71
Method 2, reduction factor 0.53						
Mean difference in flows	0.656	0.445	0.478	0.262	0.592	0.811
Mean % difference in flows	3.21	4.03	4.04	2.83	6.17	4.06
Method 3, mean bed level -0.34						
Mean difference in flows	0.621	0.439	0.487	0.267	0.436	0.450
Mean % difference in flows	3.27	3.94	4.11	2.87	4.36	3.71
Method 4, reduction factor 0.49						
Mean difference in flows	0.613	0.587	0.352	0.201	0.462	0.440
Mean % difference in flows	3.51	5.25	2.99	2.41	4.66	3.76

Finally, it must be remembered that whilst these results are valid in their own right, the fact that only very minor differences in performance exist between the different methods does not allow us to make any early conclusions about which method should be adopted for general use. This is especially so when it is further remembered that the flows at Greenholme were not particularly high. We shall thus continue to collect velocity data from the gauge at the four sites to be used this winter, and operate the gauge in the 'default' mode at present. Once suitable data have been collected we shall be able to continue this analysis to see if one approach is better than the other.

Further analysis is continuing on the stage/velocity relationship approach that produced such promising results. We are evaluating the effects of reducing the number of paths, particularly at the higher levels, and will be reporting on this in the December Progress Report.

5 WORK PROGRAMME FOR THE 1996/1997 WINTER SEASON

5.1 Selection of sites for the 1996/1997 field season

After visiting more than 20 potential sites we have identified three which we have agreed with the Project Manager and Topic Leader to be suitable for use during the 1996/1997 season; all have mains power and are considered to be at low risk from vandalism. The sites we shall be using are as follows:

5.1.1 Aldford Brook at Lea Hall (Welsh)

The site has a 3 metre wide crump weir with the concrete retaining walls extending some 2.6 metres upstream before turning into the bank. Typical stages at the site due to the Aldford Brook itself are between 0.05 and 0.6 metres. However, despite this narrow range, the stage often exceeds 1.2 metres due to the River Dee backing up. Whilst the station is some 15 km upstream of Chester weir the crest of the weir is only 300 mm above the Chester weir crest. Non-modular flows are thus caused by both high flows and high tides. The river channel has a completely flat concrete bottom some 500 mm below the weir crest, which may allow us to resolve the issue of whether or not the bottom fraction or bed height should be adjusted when setting up the gauge.

The Welsh Region have offered to issue us with telemetry alarms from the station, and to undertake gauging work during high stage events to evaluate the gauge performance. They have also offered to note the gauge status when on site, and to advise us of any problems or faults that may arise.

5.1.2 River Tern at Walcot (Midlands)

This station has a 15 metre wide standard flat V weir as the control (1:20 gradient), with the upstream bed level being some 0.6 m below the weir invert. The station becomes non-modular at very low flows during the summer due to downstream weed growth. During the winter months it is estimated that the weir becomes non-modular at stages of approximately 0.8 metres or above - this relates to Q6. The level was exceeded four times in early 1996, an untypically dry winter.

5.1.3 River Tees at Middleton in Teesdale (North East)

This site has the widest river section of the sites chosen so far, the channel being some 30+ metres wide. Stages range between 0.2 and 3 metres, with a 1.5 metre event being expected every two weeks or so. The river is extremely flashy, and velocities approaching 5 ms^{-1} have been recorded before the current meter was washed away. The station control is a shallow, non standard flat V which was repaired two years ago - the station has undergone intensive recalibration since then. The bottom is very bouldery, which is the reason for our concern about the installation, and when surveyed ranged from a few centimetres deep at the channel sides to 1.2 metres deep in the middle sections. It will thus be necessary to install the transducers a short distance into the channel, exposing them to the higher velocities. A further potential problem with the site is that it is regularly used for canoe training by local school groups, but we have been assured by the teachers that the equipment will not be interfered with.

Given the potential risks associated with this site, a fourth site had been identified as a backup should it be decided that the installation should not proceed:

5.1.4 River Churnett at Basford Bridge (Midlands)

A non-standard flat V weir, approximately 12 metres wide, forms the control at Basford Bridge. The station is unusual in that whilst the approach and exit channel has concrete banks, these are at an angle of approximately 30° to the vertical, making our present method of mounting the transducers unsuitable for this site unless modified. Whilst one might normally overcome this by moving further upstream, this is not possible here as the river turns through 80° some 35 metres upstream of the site; this is one of the few problems with this site, and might make it less than ideal for evaluating the gauge. The weir again becomes non modular at about 0.8 metres stage, equating to Q6. Five such events took place during early 1996.

We are able to reach Middleton in approximately two hours, again ensuring that it should be possible for us to be on site during some events. The journey time to Lea Hall is just over three hours, and Walcot is closer to four, traffic permitting.

5.2 Proposed work programme

The first gauge will be operated at Lea Hall with a view to carrying out the following work:

- Evaluate the ability of the gauge to work in a very narrow channel with a limited flow range;
- Confirm the 1995/1996 findings that a stage discharge relationship can be derived using a series of stage-velocity relationships;
- Try and resolve the issue of altering bed level or bottom section multiplier when determining channel discharge from the two-path velocity data;
- Look at the potential issue of u/s pooling of water below the level of the weir crest;
- Assess the performance of the gauge under eccentric non-modular conditions caused by backing up from a downstream source;
- Confirm that the 1 MHz transducers work under these conditions (we experienced problems at Low Nibthwaite during 1995/1996)
- Possibly explore the use of reflector systems, depending on time and flow conditions;
- Given that non-modular conditions will either exist for sustained periods (high flows in the Dee) or at predictable times (high tides), determine how much useful data can be collected during such events by altering the level of the transducers.

The Walcot gauge will be operated to try and address the following issues:

- Confirm that the stage-velocity method works at this site;
- Continue the work of Greenholme/Low Nibthwaite to see how the gauge performs under both modular and non-modular conditions;
- Further confirm/assess the bed level/bottom multiplier factor;
- To assess how well the gauge performs under silty conditions (the river drains a mainly agricultural area, and has a very silty bed);
- Identify how much data can be collected during a single event at a larger river section, where water depths often exceed three metres upstream of the weir;
- See if it is possible to determine a level for the two paths that will offer a compromise solution, giving acceptable data for limited work at the site;
- If time permits, and depending on our trials at Lea Hall, we may also explore the use of reflector systems at Walcot.

Whilst this work is continuing we shall be preparing the Middleton in Teesdale site for the installation of the gauge. Due to our concerns about the use of the gauge in such a flashy river, we have decided to install the racks, without the transducers, as soon as possible to allow us to observe their stability during high flows. This is especially important as the river is very shallow at the sides, and the racks will need to be installed a short distance out into the channel. If it is decided to proceed with the installation at Middleton, the gauge will be operated as follows:

- Confirm the methods developed from the previous four sites;
- Assess gauge performance in a large, deep river section;
- Confirm that it is possible to operate the equipment at such sites, typical of upland areas, without having to undertake extensive civil engineering works;
- Confirm that the stage-velocity method works at this site;
- Assess how well the gauge is able to work under very high velocities under a rapidly changing stage;
- Assess how well the gauge works in peaty water;
- See if it is possible to determine a level for the two paths that will offer a compromise solution, giving acceptable data for limited work at the site.

The fourth site has not yet been selected, although we have agreed a list of six provisional sites with the Project Manager and Topic Leader, all located in the North West Region. We shall initially be looking at sites which have either a broad crest or old mill weir as this type of structure has not been included in the work to date. If it is not possible to find a suitable site, then we shall be looking for one with a compound section, most likely a compound-crump weir. We plan to look at these sites during the last week in November, and report to the Agency by December 9 at the latest.

6 FIELD WORK ALREADY COMPLETED AT THE NEW SITES

6.1 Lea Hall

The Lea Hall gauge was installed on 31 October and 1 November. The installation took a total of 22 man hours to complete from arriving on site on the Thursday to departing on the Friday. At least three hours were spent trying to overcome a fault that had developed with one of the circuit boards on the instrument before it was decided to use the other instrument and return the gauge to Peek for inspection. Transducer counts were typically 230 (out of a maximum 255) when the gauge was initially installed, lined up using our pipe method, but increased to 255 once the suspended sediment decreased as the water had cleared (velocities were as low as 2 cm s^{-1} as the river had backed up).

Four transducers have been installed on two racks, the downstream rack being positioned just upstream of the approach slope to the weir crest on the right bank. We have mounted the racks within the confines of the concrete channel, resulting in the transducers being aligned some 50^0 to the flow. The installation was carried out with a view to evaluating the reflector system at this site, which is why the downstream rack is so close to the weir.

We managed to secure an early 'result' during the actual installation process, a result which explains the poor performance of the depth transducer at Low Nibthwaite earlier in the year. The depth transducer worked fine when the gauge was running off the 12v external supply, but it was observed that as soon as the battery was put on to a trickle charge the background noise caused by the charger corrupted the signal from the transducer. We have overcome this problem by operating the gauge off the mains supply, keeping the external 12v batteries connected as a backup should a power failure occur. Peek were unaware of this problem (they supplied the battery charger) and were unable to identify it as the cause when installing the gauge at Low Nibthwaite with us, even when using their oscilloscope.

A further visit was made to the site on November 7/8, at which time the water level had risen to a stage of 0.65 metres due to the River Dee backing up. We were able to operate the transducers at seven different levels whilst on site, but have yet to analyse this data.

6.2 Walcot

Installation of the equipment at Walcot started on 14 and 15 November, although it was not possible to complete the job as Peek had not sent back all the necessary ancillaries from the returned gauge. At the time of writing both transducer racks have been installed, and the transducers on the far rack have been connected up. We shall be completing the installation on 22 November. A total of four transducer paths have been installed at this site to allow as much data as possible to be collected during high flow events. In addition to allowing us to (hopefully) complete the work at this site as soon as possible, this will also enable us to evaluate this method of operating the gauges which offers some potential advantages for the larger lowland catchments which are often slow to fall.

PROGRESS REPORT 5 (08/02/97)

1 INTRODUCTION

This Progress Report details the progress made on the Environment Agency R & D Project W6/i646 (formerly NRA R & D Project B01 (95) 01), Calibration of Gauging Stations Using Portable Ultrasonics, between November 1996 and January 1997.

2 LIAISON WITH THE AGENCY

Following the successful installation of both gauges at Lea Hall and Walcot we requested a weekly hydrological summary from both stations, together with 15-minute level and flow data on a monthly basis. This was initially supplied by both Regions but, in recent weeks, we have only been receiving the weekly summaries for Walcot. We have thus re-requested the weekly summaries for Lea Hall, and have asked both Regions to send us the relevant 15-minute data from the sites. Welsh Region have asked that we send them copies of the 1408 data in return for them to evaluate the performance of their own equipment at the site. We shall be speaking to them directly to discuss this, but would like to take this opportunity to ask the Project Board for approval to issue them with a copy of the data.

Both the Midlands and North West Regions have sent us summary RAR data from multi-path gauges operated by the Agency. Whilst the majority of this has been historic data, it has included some from events in late 1996. We have still to receive some of the necessary supporting gauge data regarding path levels, and once we receive this we shall be able to start looking at the velocity profile distributions. Anglian Region have confirmed that they will collect data when suitable events occur.

One of the site visits to Walcot (4/12/96) coincided with an Agency Training Day being held at the station. During this the river was gauged at least four times, and the technician responsible for the station has promised to send us the data collected by the participants when it has been processed.

Following an informal meeting at Warrington in November, visits have been made to a further six potential sites within North West Region. Further discussions followed these visits and Blackford Bridge was chosen as the final site; we have recently requested a key for this station.

3 LITERATURE REVIEW

The work on the literature review has continued, with some progress being made. A visit was made to the Hydraulics Research library, and a number of papers were obtained. The visit also coincided with Jim Waters giving a paper describing the implementation of ultrasonic gauges by the Agency in the Midlands Region, and Jim has agreed to forward a copy of his notes for inclusion in the Review. We have also exchanged correspondence with Reg Herschy of CNS, and he has agreed to obtain copies of papers describing the early Harwell work for us.

The CD-ROM search of international literature is continuing, but with little success. We still hope to contact the USGS/USACE via the world wide web, having recently obtained a contact name within the organisation. We have also been advised of a list of contacts within Europe and will be contacting these to request any literature they might have.

4 WORK COMPLETED DURING THE PERIOD

4.1 Lea Hall

A total of four visits have been made to Lea Hall during the period covered by this Report. The gauge has worked well during the period, with the only data loss being due to debris covering the depth transducer in the open channel. Counts on both velocity paths have usually been close to the maximum 255 when we arrive at the site, though these quickly drop once the silt has been disturbed. The lowest counts that have been recorded during our visits were in the low 170s, still sufficient to show no errors on the gauge.

As we identified in the last Progress Report, a major problem with the site has been the frequency of non-modular flows caused by the River Dee backing up from Chester weir. Whilst this will limit the amount of high flow comparisons that can be made, it has allowed us to collect further sets of velocity profile data, this time from ten different levels (total water depth was just over 1.1 metres). Unfortunately, it has not been possible for Hydrometric Staff from the Agency to undertake gaugings at the site under these conditions, though we have recently been advised that they now have the necessary equipment to do this. We may thus delay the removal of the gauge from the site for a week or so to see if they are able to undertake gaugings under high levels in order to allow us to compare the gauged data with that obtained from the 1408.

We have started constructing a number of different types of reflector, all of which can be mounted on our transducer mounting system. When these have been completed, and water levels have risen at the site, we shall evaluate their performance and, if possible, compare the velocity profiles obtained from this method with those obtained from the standard path configuration. We plan to start this work around 23 January if conditions allow.

4.2 Walcot

The Walcot installation was completed on 22 November, although at that time there was still a problem with the unit's visual display board; this was replaced on the next visit on December 4. As with Lea Hall the transducers were lined up by sight rather than oscilloscope, and counts of 255 were obtained at the first attempt.

One event has occurred at the site since the installation was completed, spanning the period 19-21 December. The gauge worked throughout the whole event, with only a few dropouts being observed in the lower path during the peak flows, most likely due to high sediment concentrations. An initial analysis of the gauge data, downloaded yesterday, shows that the gauge significantly under-gauged the peak flows during the event, which reached a peak stage/flow of 1.4 metres/28 cumecs. This was expected as the station control is a flat V weir and both transducer paths were below the highest level of the crest (the path levels were -0.2 and +0.1 metres relative to the weir invert). The higher path has now been raised to +0.4 metres, level with the weir crest. After data have been collected from this level the top path will operate at +0.8 metres, and the lower path will be raised to 0 metres.

The Agency have recently commissioned an automatic flushing system for the crest tapping at Walcot. This has allowed them to collect what is thought to be accurate data during non-modular conditions. Richard Iredale has agreed to send us copies of the data once it has been processed to allow a three-way comparison to be made between 1408, theoretical and stage/discharge derived values for non-modular flows.

It should be noted that, given the present situation with four sets of transducers at different levels, we hope to get on site during one of the next two events to collect data from as many of the four different levels as possible. We will then be able to move all four transducer paths up *en masse*, increasing the amount of potential data that can be collected from a fixed number of events. With this in mind we shall be asking the Midlands Region to issue us with an alarm from the station.

It can thus be seen that, even if we do not manage to get to the station during an event, two more events will result in us obtaining data from five different levels. It is likely that by this time we shall have to remove two of the four transducer sets for use at Middleton. We will continue to operate the gauge with two paths; the lower path will be operated at levels below the highest point on the weir crest, whilst the upper path will be used to collect data from higher levels. The installation will allow us to collect data from paths as much as 2.5 metres apart should conditions allow.

4.3 Middleton in Teesdale

The steelwork to mount the transducer racks for Middleton was fabricated during early December and successfully installed on 20 and 21 December during relatively low flow conditions. Given the very flashy nature of the river, and the bouldery/rock bed, we decided to concrete the steelwork in position; some of this had to be cast underwater and an inspection carried out earlier this week showed that this had been successful. We have still to inspect the site once more during high flows before moving the gauge from Lea Hall and half of the transducers from Walcot. It should be noted that due to the channel geometry it will not be possible to get the lowest path any lower than 0.4 metres above the weir invert - to get it any lower would have meant that we were only able to collect velocity data from the middle 80% of the channel, and path lengths would have been significantly reduced. This is a simple function of this type of site - a relatively steep channel gradient reduces any pooling upstream of a control structure, thus the channel tends to be more shallow.

5 SELECTION OF THE FINAL SITE

As previously mentioned, a further six potential sites have been visited to assess their suitability for use as the final site. After discussions with some of the Project Board it has been decided to use Blackford Bridge on the River Roch. This station will allow us to evaluate the equipment under conditions typical of many gauging stations in the UK where an existing mill weir has been adopted as a stable bed control. There is no cableway at the site, so we shall either have to find an alternative method of getting the cables across the river or, depending on the success of the trials at Lea Hall, install the gauge with a reflector system. The first option is more likely as the channel is at least 20 metres wide.

As the station is in the South Area of the North West Region the Agency have offered to loan a third 1408 gauge for use at the site. Peek have advised that it will be possible to adapt the gauge to work with the spare Psion and, once we have received approval from the Project Board, we shall install the gauge as soon as possible. This will allow us to operate three gauges simultaneously for the remainder of the project, hopefully allowing us to collect as much data as possible. This will be particularly useful for Walcot, where the comparisons can be made against good quality data collected by the Agency.

Finally, we feel that we should perhaps add a note of concern at this stage in the Project regarding the lack of high flow events that have taken place. Although we are currently half way through the second winter season there has been only one high flow event of any significance, despite the prolonged dry period/drought having ended in autumn 1996. Whilst we are hopeful that events will occur during the remainder of the winter, and that this is particularly likely at Middleton and Blackford Bridge, we are aware that the data that have been collected to date will not be sufficient for a full and fair evaluation of the equipment to be made. Clearly the availability of a third gauge significantly increases the chances of suitable events being recorded, and has allowed us to select sites of mixed qualities (ie some with very high data quality but a lower incidence of high flows, and others where there is a lower confidence in the quality of the high flow data, but where high flow events are more likely to occur due to the river being more flashy). This is likely to result in us continuing with the monitoring until later than originally planned, which may have an effect on the timing of the production of the final Reports. We shall continue to keep the Agency informed of the likelihood of this in future Progress Reports.

6 SUMMARY OF REQUESTS MADE IN THIS REPORT

A number of requests for information, data and approval have been made in this Progress Report. Given that we are already into the second half of the final winter season, and some of the requested information is needed before work can continue, we feel it is useful to summarise the requests that have been made:

1. Approval for Peek to supply an additional set of EPROMS and cables for the third 1408 at a cost of £250;
2. Approval to purchase additional cables and connectors to install the gauges at Middleton in Teesdale and Blackford Bridge, unlikely to exceed £150;
3. Approval for us to increase our mileage rate from 18 to 21 pence per mile;
4. Approval to supply the Welsh Region with data collected from the Lea Hall site;
5. A key for Blackford Bridge gauging station;
6. Approval to remove the gauge from Lea Hall once we have evaluated the reflector systems.

Additional requests for individual Regions will be followed up with the relevant personnel.

PROGRESS REPORT 6 (25/02/97)

1 INTRODUCTION

This Progress Report summarises the progress made on the Environment Agency R&D Project W6/i646 (formerly NRA R&D Project B01 (95) 01), Calibration of Gauging Stations Using Portable Ultrasonics, between January and February 1997.

Whilst, according to the PID and Scoping Report, the report is scheduled to contain a summary of the work completed at Sites 3 and 4 (Lea Hall and Walcot), along with the associated site reports, the lack of high flow events during the 1996/1997 winter has caused a delay in the completion of the work at these sites. This, combined with the dry winter of 1995/1996 at Sites 1 and 2 (Greenholme and Low Nibthwaite), has resulted in the Project currently being behind schedule, and there is now a significant risk that we shall have insufficient information to allow the Project to be satisfactorily completed on time.

Both SWS and the Agency recognise this risk, which was included in the original PID, and a meeting was held at Warrington on Thursday 13 February to discuss the situation. It was agreed that SWS would summarise the progress that has been made on the Project, outline the anticipated results that could still be obtained during the remainder of the current winter, and propose a revised schedule should it be necessary to extend the duration of the Project. These matters are thus dealt with in the latter stages of this Progress Report, along with the associated financial and contractual implications.

2 LIAISON WITH THE AGENCY

Both North West and Midlands Regions have continued to send us details of RAR II output from existing gauges, along with the station information needed to allow us to study the path velocity data. We are currently looking at these data to see if it is possible to identify an optimum level for two paths within the existing gauge configurations.

Whilst visiting all Agency Regions on another R&D Project we have identified a number of further potential sources: Thames Region actually log velocity data and will forward this once they have experienced an event; Anglian Region have agreed to obtain RAR data if/when they get any events; and a site in south Wales has a gauge installed upstream of a fully rated, flat V weir from which we have also requested information.

We have received keys for both Blackford Bridge and Middleton in Teesdale gauging stations, and collected the third gauge from Warrington on 13 February. This coincided with an informal meeting with the Project Board to discuss the progress that has been made in light of the extremely dry conditions that have been experienced during the course of the Project.

An alarm has been set up from the Walcot telemetry unit, and this will be sent to a message pager ensuring that we are on call on a 24 hour basis - this is becoming increasingly important with the lack of high flow events. Midlands Region have also sent us data from the (only) event at Walcot in late December. This includes level data from both upstream and crest-tapping wells, along with stage-discharge derived flows and those derived using the crest-tapping values to reduce the theoretically derived flows. Initial analysis suggests that the crest-tapping data need further analysis as the flows derived from this method are consistently and significantly below the values of both the gauge and stage-discharge data.

Finally, we have been informally asked by Jim Waters whether or not we are able to give a presentation to the National Hydrometric Meeting in October 1997. Our response to this was positive, but we also pointed out that the Project might still be continuing and the presentation would thus be more of a Progress Report rather than presenting the final results and recommendations.

3 LITERATURE REVIEW

The early work in trying to identify and obtain literature for review is finally beginning to bear fruit, and we have managed to obtain a number of useful documents and further leads in the period covered by this Report. Reg Herschy has sent us a total of 12 papers documenting the early Harwell work and subsequent reviews; many of these papers are the only copy known to still exist! Jim Waters has also sent a set of notes from his recent presentation describing the development of the ultrasonic gauge network in Midlands Region.

Possibly of greatest use, certainly for future documents, is a pair of papers we have managed to receive from USGS. One of these regards the effects of horizontal velocity variations and proposes that, in certain channel types, a two rather than one-dimensional velocity profile should be used. The second paper describes the findings of studies looking at different reflector systems and, more encouragingly, was presented at a workshop on the applications and operations of ultrasonic gauges in Florida in August 1992. We are currently trying to determine whether any papers from this workshop are available to researchers outside the USGS.

4 WORK COMPLETED DURING THE PERIOD

4.1 Lea Hall

Two visits have been made to Lea Hall during the period covered by this report. The first was in late January to check the equipment, and the second was over the weekend 15-16 February to try out different reflector systems. No other work has been possible at the site due to the very low flow conditions that were experienced during January - this was, for many raingauge sites, the driest January on record.

The full details of the reflector work carried out at the site will be included in the site report which will form part of a later Progress Report. However, we are able to advise that the trials were successful in that we managed to get one of the five different reflectors to work, giving velocity readings consistent with those from the single path. The reflector was only tried over the higher of the two paths as it was decided to use the lower path as a control. The site report will contain details and photographs of the different reflectors that were used, along with analysis of the results that were obtained.

It has been agreed with the Project Manager that we shall remove the gauge, cables and transducers from Lea Hall as soon as possible. The gauge and cables will then be used at Middleton, together with half of the transducers from Walcot when they become available. As the transducers from Lea Hall are not suitable for using at any of the remaining sites we plan to keep them mounted on the removable racks in their aligned positions so that, if possible, we can return to Lea Hall later in the year to carry out further work with the reflector systems. It has also been decided to leave the mounting systems *insitu,* particularly as they are not ideally suited for using at any of the other sites.

4.2 Walcot

As with Lea Hall, the very dry conditions have meant that it has not been possible to get any useful work completed at Walcot during the period covered by this report. River levels have only varied by 35 mm over the whole of January, resulting in only two visits being made to check the condition of the equipment. On one of these visits it was necessary to clear the transducers of weed and other organic debris, and on the other it was found that the Psion had stopped logging for no apparent reason. Both of these incidents serve to demonstrate the usefulness of the routine check visits as they increase the chance of successful data collection when an event does occur.

The current situation at the station is that the river appears to have risen above baseflow conditions, with the present level (0.495 m ASD) being more than 130 mm above that at the start of the month following the rainfall of the past two weeks. Both we and the Regional hydrometric staff feel that the river will respond to the next significant rainfall event in the area if it occurs in the next two weeks, and it has thus been agreed with the Project Manager to leave the four paths (ie eight transducers) in at present to allow as much data as possible to be collected from the site. Once the next event has occurred four of the transducers will be removed for use at Middleton.

This dependency of the equipment on the location of the transducers is likely to be the focus of one of our recommendations arising from the research. We are already of the opinion that the use of the equipment could be significantly enhanced by having more than one set of transducers per gauge, as this will allow a number of sites to be 'prepared' by installing and lining up the transducer racks. The gauge itself can then be held at an Area or Regional office and, on receipt of an alarm from the relevant station, could then be deployed at a station in under an hour. The flexibility of the equipment could be increased even further by having more than two paths installed at appropriate stations, although we realise that by adopting this approach the portability and cost-effectiveness of the equipment may be reduced. To give an example, if we had had sufficient sets of transducers we could have had Walcot, Middleton and Greenholme set up as prepared sites for this winter. The gauge could have been used for the December event at Walcot, removed during the dry weather in January, and then deployed at either Middleton and/or Greenholme during the past two weeks when a number of events have occurred at both sites. The gauge could then be moved back to Walcot once the River Tern had begun to respond to rainfall events once more.

4.3 Middleton in Teesdale

We have only visited Middleton in Teesdale on one occasion this year to inspect the steelwork at the site following a minor event that occurred in late December. We have been advised by the Field Data Services that the second highest event ever recorded at the station occurred last week, when our steelwork was submerged by over a metre, and we plan to revisit the site later this month to assess the structure before installing the gauge.

5 SUMMARY OF PROGRESS MADE ON THE PROJECT

In summarising the progress that has been made so far on the Project, it is necessary to differentiate between the results obtained and the effort expended. This section of the Report will thus deal with each of these issues in turn, comparing the actual situation to that originally proposed in the PID, Tender and Scoping Report. Whilst the matter of theoretical work and analysis will be dealt with, the focus will be on the amount and success of the field work that has been possible.

5.1 Results obtained to date

In assessing the results that have already been obtained it is perhaps useful to restate the Project objectives originally set out in the Project Initiation Document (PID):

To identify practical problems of application and limitations on the method.
To determine the accuracy of the equipment under a range of conditions from ideal to the borderline of application.
To determine the optimum configuration.
To recommend a standard practice where this is feasible.
To note areas of remaining uncertainty in the accuracy of the results.
To assess typical costs of the method based on realistic equipment costs and life, and manpower requirements.
To test and report on performance of ultrasonic equipment at structures over a range of mainly high flow and non modular conditions. The structures will have an existing accurately known modular rating and will also be typical sites for future application.
To use any existing suitable Ultrasonic Gauging Station in a manner which replicates the portable equipment.
To produce a Report on each site tested (no more than 3 months after each site has been completed), which will be incorporated into the final Project Record.

If the Project continues as planned we feel that, based on the results that have/have not been obtained so far and the amount of information we have still to analyse, it will be possible to completely satisfy objectives (f), (h), (i) and (j) within the timescale. We feel that it will also be possible to partially satisfy objectives (a), (e) and (g), and to comment on the remaining objectives, though the uncertainty in the assessments and associated recommendations will be significant. It can thus be seen that whilst the peripheral objectives can be fully satisfied, namely the analysis of data and writing of reports, those of a more fundamental nature such as the field trials and recommended practice(s) will be left unresolved to varying degrees.

The reason for this apparent lack of success is the weather conditions that have existed during the course of the Project - the 22 month period to the end of January 1997 was the driest on record. This issue was first noted in the first Progress Report to be produced for the Project (28 February 1996) in which we stated 'the greatest single problem that the project faces is the lack of suitable high flow events in which to evaluate the equipment'. This concern has been raised in every subsequent Progress Report. We can try and put this dry spell into perspective with the following information:

After more than six months monitoring at Low Nibthwaite the river levels had all been within a range of 509 mm.

Whilst we managed to obtain useful data from Greenholme over five 'events' that occurred during the six month monitoring period, only one of these events had a range in levels of over 900 mm; for three of the events the water levels varied by less than 600 mm. When starting work at the site we had identified that, in a typical January-March period, we could expect an event of greater magnitude approximately every 10-14 days, with at least four events experiencing a range in levels of closer to two metres than one.

Before we decided to use Walcot as a study site Richard Iredale of the Midlands Region undertook some preliminary analysis of level data to allow us to identify the frequency of high flow events. A stage level of 0.875 metres has been exceeded for 6% of the flow record measured over a 35 year period, ie typically 22 days a year. The level was exceeded four times between January and October 1996, which was a very dry period. However, in the five winter months that have followed, **only one event of this magnitude has occurred**, lasting for less than a day above this level.

We feel that these points clearly demonstrate the exceedingly dry nature of the period over which the Project has been carried out, and explain why we feel that it will not be possible to fully address all of the objectives outlined in the PID. It must also be noted that, even though their timing has been variable, we have managed to collect data from every single event that has taken place during the course of the Project, and have been on site for all but one event.

Notwithstanding the lack of suitable events, we have still managed to obtain a number of useful results which are summarised below. Some of the findings (marked with an *) have been reproduced at more than one site.

Greenholme
The viability of a 12v power supply was established, together with using the Psion as a datalogger.*
Assessment of typical deployment times and costs.*
Assessment of aerial routing of cables.*
Confirmation that the gauge works in rivers of >25 metres width.
Assessment of our method of mounting the transducers.*

Assessment of lining up the transducers by eye.*

Confirmation that the gauge works under varying flow conditions, albeit with some potential problems at high levels, thought to be due to high suspended sediment concentrations.*

Confirmation of extrapolating the gauge results over a limited range, but because of a lack of high flow events, we were not able to monitor beyond the 'break-point' in the stage discharge relationship.

Problems with gauge performance due to a variety of reasons, most notably the power supply.*

Problems with the depth transducer silting over.

Problems with the design of some of the gauge components.*

There is potential in deploying at least one of the paths in a diagonal alignment (relative to the horizontal) but, as with many of the results, this has yet to be confirmed.

Problems with the depth measurement if both velocity paths are out of the water, due to an assumed velocity of sound.

The minimum cover recommended by Peek for each of the velocity paths can be significantly reduced (by as much as 90%) given suitable channel conditions.*

A methodology for deriving a stage-discharge relationship was derived, although this has yet to be tested for another site.

Low Nibthwaite

Problems associated with using battery chargers and their associated electrical interference were identified.

Confirmation that both 1MHz and 500 kHz transducers were able to work in a channel of approximately 10 metres width.

Possible problems with velocity paths needing high velocities to work under turbulent/aerated conditions.

Lea Hall

Confirmation that, suitably deployed, the gauge can be used to obtain detailed velocity-profile information in a very short time.

Confirmation that the 1 MHz transducers work in small (<3 m wide) channels.

Confirmation that the gauge works from a 240v supply.*

Trials with reflector systems resulted in one success.

Confirmation that the gauge works under very low velocity conditions, caused by downstream backing up.

Walcot

No additional results have yet been obtained from this site.

From these summary points it can be seen that whilst the early work at Greenholme and, to a lesser extent, Low Nibthwaite may have yielded a number of useful results and has allowed us to develop a proposed methodology, we have not yet been able to fully evaluate the equipment and/or methods over a significant range in flows at any one of the four sites used so far. Ironically, had we left the equipment in at Greenholme this would have been possible over the past two weeks, but it was agreed that the Project would potentially benefit more if the gauges were moved to new sites.

5.2 Effort expended on the project to date

We have already expended a similar amount of input to that planned at this stage in the Project. With the exception of categories (e) to (j) from Table TS2 in the PID which are primarily concerned with the final analysis and preparation of reports etc, there is only one area (Operate gauge & collect data) where expended effort significantly differs from that anticipated - our field operative has spent 14 days less than planned in this work area, mainly due to a lack of routine work other than battery changing at Greenholme in the first winter season, whilst Tony Bennett has spent more than twice the anticipated time operating the gauge due to three reasons:

The problems that have been experienced with the gauge at Greenholme (transducer board), Low Nibthwaite (difficulties with the depth transducer and background noise) and Walcot (processor board, power supply and LCD board) have meant that it has been necessary to make more trips than necessary to deal with these technical issues;

The lack of events meant that the collection of data during any events that have occurred has been of greater importance; because of this we decided that Tony should visit the sites during these events to monitor the gauge performance and supervise any work on site;
Monitoring continued much later than anticipated at the first two sites in an effort to collect as much data as possible given the lack of events.

The final row of Appendix A contains our estimate of the total amount of effort that will have been expended by the end of the Project, should it be decided to finish on the due date and stop fieldwork at the end of March. These figures have been based on the installation work at the two remaining stations, three further trips to each of the three final stations, and project management/data analysis/report preparation as specified in our tender and Scoping Report. Again, it can be seen that with the exception of Tony Bennett, the effort expended is largely as planned.

6 PROPOSAL TO EXTEND THE PROJECT

It has already been shown that, due to the exceptionally dry nature of the winters over which the Project has been carried out, it has not been possible to address the majority of the key objectives identified in the PID, including:

The operation of the gauges over a range of mainly high flow and non modular conditions;
To determine the accuracy of the equipment under a wide range of conditions from ideal to the borderline of application;
To determine the optimum configuration;
To recommend a standard practice where this is feasible;
To note areas of remaining uncertainty.

In our opinion these objectives form the main focus of the Project yet, at best, we feel that it will only be possible to partially fulfill them within the scheduled timescale. Whilst the current month (February 1997) appears to be somewhat wetter than normal, it follows the driest January on record and many rivers have still to produce significant flows. Our assessment of time inputs to the end of March is based on a 'normal' month, ie we should experience 2-3 events at each site. Even if this occurs, we shall still have insufficient data to allow the analysis to continue on a sound footing. Consequently, we feel that if the effort and financial resources already expended on the Project are not to be wasted it will be necessary to extend the duration of the Project to allow data to be collected from more high flow events.

Based on the results and provisional methodology developed at Greenholme, we feel that it will be necessary to collect data from between 6 and 8 events at each of the three remaining sites (Walcot, Blackford Bridge and Middleton). As the Greenholme data were only collected at low to medium flows, we consider that it will be necessary to operate the equipment over the following ranges at each of the sites:

Walcot	All events to have a range of >600 mm in water level, with two peaking at a stage of over 1.2 metres;
Blackford Bridge	All events to have a range of >600mm , with two >1 metre range in levels;
Middleton	All events to have a range >1 metre, with two events peaking at a stage of between 1.6 and 2 metres.

These requirements are based on provisional analysis of received data; they may be adjusted once we receive the flow duration curves and stage records for Middleton and Blackford Bridge that have been requested.

PROGRESS REPORT 7 (16/3/98)

1 INTRODUCTION

This Progress Report summarises the progress made on the Environment Agency R&D Project W6/i646 (formerly NRA R&D Project B01 (95) 01), Calibration of Gauging Stations Using Portable Ultrasonics, during the twelve month period prior to March 1998. The Project was officially in a state of dormancy for over half of this period, between early summer and late autumn, although some routine maintenance work was completed at the sites to ensure that the equipment was still working.

In contrast to the two previous winters, recent months have seen a return to wet conditions. Whilst this period has been far from exceptional, and still drier than normal in many areas, it has allowed much more data to be collected for the Project than previous field seasons. As this work is still ongoing, and events are still taking place, it has been agreed with the Project Manager that this report will:

1. Summarise the work that has been completed at each site, and the data that have been collected.
2. Outline the work that is still to be undertaken in the field studies, and the aims of this. In particular, the report will suggest at what point there will have been sufficient data collected to enable the field studies to be completed at each site.
3. Indicate the analysis that is to be undertaken on the data, and outline a timescale for this. This will, in turn, depend on receiving quality controlled data from the Agency offices operating each of the gauging stations.
4. Suggest a timescale for the completion of the Project, relating completion date to the end of the field studies rather than a specific date.

2 LIAISON WITH THE AGENCY

A presentation was made at the National Hydrometric Seminar in Coventry on 4th November 1997. Rather than try and summarise all of the results that have been obtained from the Project, and cover all of the field sites, the talk concentrated on the results that were collected from Greenholme in 1995/1996, and the methodology that these results have helped to develop. The talk appears to have been well received, and a number of Agency personnel have provided positive feedback on the issues that were raised. In addition to this, the talk also appears to have stimulated further interest in portable/small ultrasonic gauges, with manufacturers reporting a number of new enquiries following the presentation.

The majority of the liaison with the Agency has been of a routine nature, and relates to the three field sites that are currently in use. We would particularly like to thank Ben Perry of Field Data Services in North East Region who has enthusiastically been providing weekly summaries and monthly data on disc for Middleton in Teesdale since last autumn. The data have been provided on a relatively intensive basis as the station telemetry system cannot be directly accessed by SWS, and is has been difficult to obtain current information from the Agency. The weekly summaries have therefore been useful in enabling us to schedule site visits.

Thanks also go to staff in Midlands and North West Regions who have been providing data for Walcot and Blackford Bridge on a less intensive basis. The Sale office of the North West Region have advised us on a number of occasions when there appeared to be a fault with the gauge, most notably when the cables were washed out during the late summer, and provided data on disc at very short notice following a significant event in January 1998.

A visit was made to the Reading offices of Thames Region to discuss the problems that they have been experiencing with ultrasonic gauges at one of their sites. Jim Hawker described the different gauges and configurations that have been used, and the problems that have been experienced. The present thinking is that the intermittent poor performance of the gauge may be linked to differential heating of the almost stationary channel due to shade on one bank, or poor mixing of inflows from an upstream tributary. The problems do not appear, at present, to offer any real assistance to this Project as they are so site specific and relate only to very low flows on warm summer days.

The Project Manager forwarded an E-mail message from Southern Region to all Agency staff asking if any of them have experienced problems with silt/sediment concentrations causing ultrasonic gauges to fail. Our reply was that we believe this has been a problem at a number of our sites (most notably Greenholme and Middleton, and possibly Blackford Bridge). However, as the Agency had decided not to commission the proposed additional option to the Project to look at this issue we were unable to be more constructive.

3 WORK COMPLETED DURING THE PERIOD

3.1 Introduction

The decision to extend the Project by another field season appears to have been justified, with events having been recorded at each of the field sites. In particular, the early part of 1998 has contained a number of wet periods, particularly in the west. The eastern catchment (Middleton in Teesdale) has experienced fewer events.

Whilst the data collected from these events has been processed, and analysis commenced, the analysis has yet to be completed. However, sufficient information is available to assess what has been achieved in terms of data collection, and the purpose of this section is to summarise this. Section 5 will outline what additional data and studies may be of further benefit to the Project, and at what stage studies should be completed at each of the sites.

3.2 Middleton in Teesdale

Of the three field sites that are currently in use the results from Middleton are the most disappointing. A significant amount of effort has been spent trying to improve the gauge performance, but with little success. In all but one instance the transducer paths have failed when the water level rises above one metre stage datum; in some cases this has occurred at levels as low as 0.65 metres. It is strongly suspected that this is due to high sediment concentrations within the channel, but there are no data to confirm this. It has been noted during a number of events that the gauge is able to work at a higher level during the rising limb of the hydrograph, possibly arising from the differences in entrainment and transport/settlement velocities of the waterborne sediment.

In order to try and address these problems (and partly because it is not possible to get the lower path below 0.4 MASD) the transducer paths have only been operated at four levels, as shown in Table 3.1. The paths have recently been raised to 0.7 and 1.3 MASD. A number of transducer configurations have been tried, at voltages ranging from 200 to almost 700v, with different transducers being tried in different positions and the alignment being repeatedly checked.

Path level (MASD)	Minimum stage	Maximum stage
0.4	0.15	1.032
0.5	0.15	1.701
0.7	0.75	awaiting event
1.0	1.05	path did not work
1.1	1.15	path did not work
1.3	1.35	awaiting event

Table 3.1 Transducer path levels that have been used at Middleton in Teesdale during the course of the Project, together with summary details of the range in water levels that have been monitored. All levels are relative to stage datum, and are in metres. 'Maximum stage' represents the maximum stage at which the gauge worked.

It is not known why the gauge performed so well during the January 1998 event when velocities were recorded at levels almost twice those of all other events, but possible reasons include:

- Given the time of year, a large part of the fine sediment may have been frozen within the soil matrix.
- The event was the highest recorded at the site during the Project. Under these conditions, the supply of available sediment may have been exhausted (the gauge had failed at earlier levels, but started working again for a short period at the higher flows).
- A conflicting explanation to this is that the event was so severe in its intensity, ie the rising limb was so steep, that sediment from higher up the catchment may not have reached the gauging station at the time the velocity paths were working. The gauge did subsequently fail once again, before restarting at lower levels.

Whilst these different explanations are all plausible, they are based on conjecture arising from incomplete information. None the less, they do provide a result for the Project, albeit a negative one, in that they demonstrate a weakness to the equipment. We have had many lengthy discussions with the equipment manufacturers about this situation, and their general opinion is that the equipment is likely to have a particular threshold at any site beyond which it will not perform. The conditions which are most likely to affect performance are sediment loads, air entrainment and electrical interference. With multi-path gauges it is usually possible to alter the gain (amplification) of the signal for each path, whereas with the 1408 a single gain setting applies to all velocity path and depth measurement signals. This lack of variable control in the equipment gain settings is reflected in the price, ie it is a case of you get what you pay for, but Peek are aware of these concerns and are considering modifications that may overcome the problems. Another potential solution is described in Section 4, which it is hoped to evaluate during the remainder of the Project.

3.3 Blackford Bridge

As the gauge at Blackford Bridge had been loaned to the Project, and the gauging station is located in an urban area, the installation was undertaken in a slightly different manner to that at the other field sites. In particular, the cables were all routed underwater, across and along a sizeable channel with an irregular bed. The cables were all tied to galvanised steel cables which were in turn tied to or threaded through concrete blocks. Following reports from hydrometric staff working at the site a number of visits were made to clear weed from the cables during the summer months - it is estimated that almost 1 tonne of weed was removed on one of the visits. Despite these efforts the steel cables were eventually broken during a relatively minor event (believed to be in August). All remaining cables and transducers etc were then removed for salvaging.

The cables were reinstalled in the river in October. Instead of using steel cables once more it was decided to use galvanised short link anchor chain. 3/8" chain was used and, to date, has been most successful despite two major events having occurred. Whilst using the chain does present potential problems relating to manual handling legislation because of its weight, it was found that in practice it was much more straightforward to use than the steel wire and concrete block combination. By carrying the chain in a number of bins it was possible for two people to safely manhandle the chain from field vehicle to riverbank. Once on site, a catenary rope was then used to assist with pulling the chain across the river. A big advantage to using the chain is that it lies flush to the river bed and can be pulled back upstream following major events which have caused it to 'creep' downstream a little. It should also be longer lasting than the steel cable should it be used for a permanent installation.

The first big event of the Project to occur at Blackford Bridge was in January 1998. The Agency quickly provided their data on disc, together with supporting information, and a preliminary analysis of the gauge data was then undertaken. This was forwarded to the Agency as they are currently developing a flood defence scheme for the catchment and have engaged external consultants to reassess the rating for the site. This preliminary analysis is contained in Appendix A.

A number of issues were raised as a result of this event, notably the accuracy of the stilling well levels due to the proximity of the well to the weir crest, and problems with the gauge measuring depth due to the transducer having been moved when the well was pumped. Despite moving the transducer this problem re-occurred during an event of similar magnitude in February. The depth transducer has been re-sited once more, this time away from the steps in the well walls, and hopefully the problem has been resolved.

A summary of the level/velocity data that have been collected to date is given below in Table 3.2, and illustrated in Figure 3.1. It can be seen that if a further event allows data to be collected from the existing levels (0.4 and 0.8 MASD) a total of six different path levels will have been used. Following this it is intended to place the lower path at 0.1 and raise the upper path to 1.2 metres. The next step after this will be -0.1 and 1.0 metres, although it must be noted that experiences to date suggest that the probability of experiencing three further events of sufficient size to allow data to be collected from these higher levels is low. None the less, it is considered that this information will be more useful to the Project than trying to 'fill in' the gaps between the existing path levels, as an interval of 0.2 metres is considered to be sufficient for a channel of this size.

Table 3.2 Transducer path levels that have been used at Blackford Bridge during the course of the Project, together with summary details of the range in water levels that have been monitored. All levels are relative to stage datum, and are in metres.

Path level (MASD)	Minimum stage	Maximum stage
-0.1	0.08	0.42
0	0.1	1.2
0.2	0.08	1.45
0.4	0.4	Awaiting event
0.6	0.6	1.2
0.8	0.8	Awaiting event

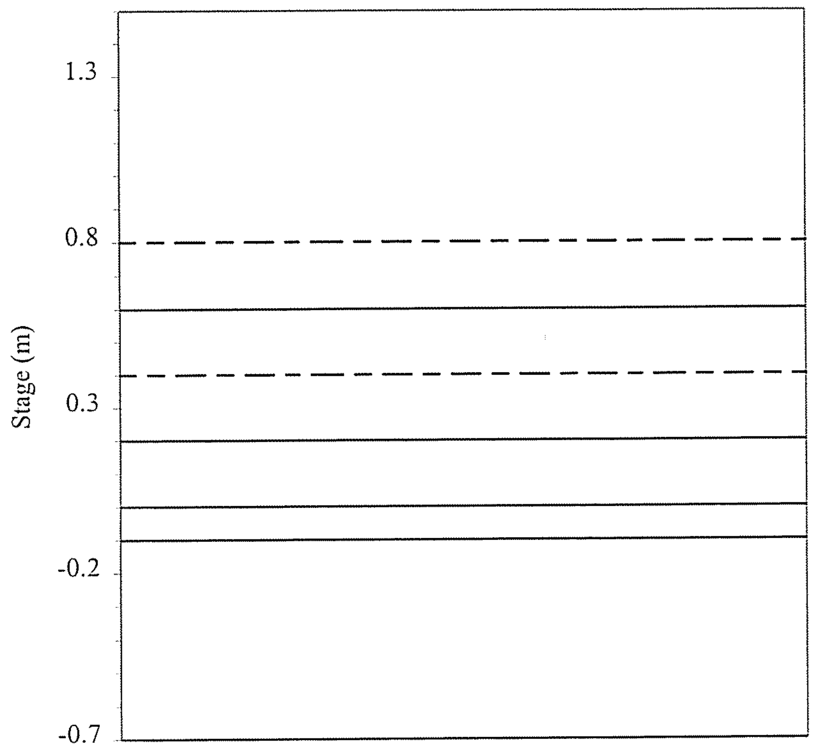

Figure 3.1 Pictorial representation of the different levels at which transducer paths have been deployed at Blackford Bridge. All levels are relative to stage datum. The dashed lines indicate the existing transducer positions, from which data have yet to be obtained.

3.4 Walcot

The studies at Walcot have potentially been the most successful of the whole Project, with data having been collected from many different path levels over a wide range of elevations, as shown in Table 3.3 and Figure 3.2. Of particular benefit is the fact that the Agency have a good quality calibration for the site, being based on the weir equations for low flows and current meter gaugings above the modular limit. Further confidence is provided by the fact that the station also has an operational crest tapping, enabling a subset of the non-modular flows to be further verified.

The gauge has performed remarkably well at Walcot, with data failing to be recorded on only two occasions. One of these was when the downstream set of transducers became ragged up by a fertiliser bag, and the other was when the depth transducer failed (even then both velocity paths continued to function, enabling data to be collected for use with the Agency level data).

Data have been collected from every event that has occurred at the site and, in the majority of cases, this has included both rising and falling limb data to enable comparisons to be made. SWS personnel have been on site for all but one of the events, enabling transducer path levels to be adjusted. In some cases this has resulted in two sets of data being collected from each event (ie from four path levels), an advantage provided by the relatively slow and predictable hydrological response of the catchment. This had been part of the basis on which Low Nibthwaite had been selected as a field site at the start of the Project, and confirms that it is possible to use the equipment in different ways for different conditions.

Table 3.3 Transducer path levels that have been used at Walcot during the course of the Project, together with summary details of the range in water levels that have been monitored. All levels are relative to stage datum, and are in metres.

Path level (MASD)	Minimum stage	Maximum stage	Range
-0.1	0.4	1.41	1.01
0.1	0.4	1.36	0.96
0.2	0.4	1.41	1.01
0.4	0.4	1.36	0.96
0.5	0.5	1.91	1.41
0.6	0.6	awaiting event	
0.8	0.8	1.91	1.11
0.9	0.9	awaiting event	
1.0	1.0	1.82	0.82
1.3	1.3	1.82	0.52

We have yet to receive the Agency data for this site and, to date, have only been able to undertake a limited analysis of the data. Results are encouraging, with strong stage-velocity relationships being observed in the data that has been processed thus far.

One feature was noted when analysing the data collected in December 1996 for another Agency R&D Project concerned with the derivation of non-modular flows over flat V weirs. The only significant event to have occurred that winter contained two peaks, the first being smaller than the second. Differences were noted between the stage-velocity and stage-discharge relationships of the two components of the event. Observations of the channel before and after the event suggest that these differences may have been due to the flattening of weed on the channel bed up and downstream of the weir. An extract of the analysis is included in Appendix B.

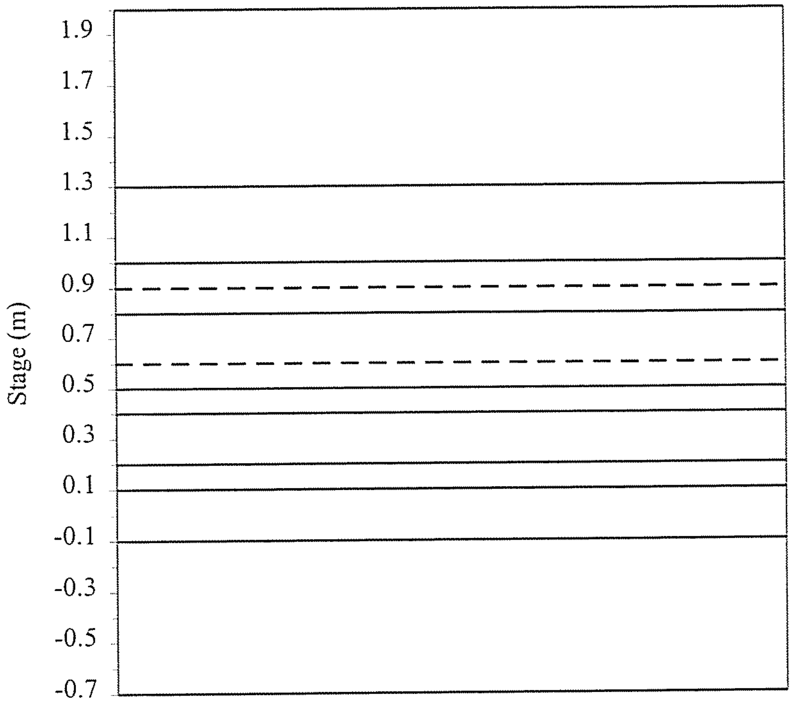

Figure 3.2 Pictorial representation of the different levels at which transducer paths have been deployed at Walcot. All levels are relative to stage datum. The dashed lines indicate the existing transducer positions, from which data have yet to be obtained.

4 RECOMMENDATIONS FOR FIELD WORK STILL TO BE UNDERTAKEN

4.1 Introduction

It can be seen from Section 3 above that significant progress has been made during the additional winter field season to enable the Project objectives to be met. In particular, data have been collected that will enable:

- The performance of the gauges to be evaluated;
- A comparison of gauge and Agency derived flows and station ratings;
- An evaluation of different methods of deploying the gauges, depending on both site and hydrological conditions;
- Potential weaknesses in gauge performance to be identified;
- Typical operating costs to be derived for using the gauges.

There is, however, still useful work to be undertaken at the field sites. Whilst some of this may be considered to be desirable rather than essential, some of the work is considered to provide significant further benefits to the Project. The recommended work is thus detailed for each of the gauging stations.

4.2 Middleton in Teesdale

As indicated in 3.2 above, the gauge performance at Middleton has been poor during medium to high flows. This is thought to be due to high suspended sediment concentrations, although air entrainment might also be to blame. It is considered by both SWS and Peek that, with the current gauge configuration and transducers, these problems are not likely to be overcome, and that it will only be possible to derive a rating curve for low-medium flows at the site. It is thus recommended that the existing field studies are only continued on a limited basis with the transducer paths at their existing levels.

The transducers that are currently installed at the site work at a frequency of 500 kHz. Peek are currently trying to obtain a pair of 200 kHz transducers which can then be tried on one of the paths for a limited period. These transducers will have 'more punch' than the 500 kHz units and are more suitable for use at a site where there is a long path length and high sediment loading. It is considered that the probability of a suitable event (ie maximum levels greater than one metre) occurring within the next four-six week period is high, and it is recommended that the transducers are evaluated at this site.

Should the new transducers solve the problem it is still unlikely that it will be possible to collect sufficient data to allow a full stage-discharge relationship to be derived for the site due to constraints on time, probability of significant events and limited data. However, a most useful result will have been obtained, namely confirmation that the equipment can work under adverse conditions, and it will provide the Agency with the necessary information to specify potential changes to the gauges to the manufacturer.

4.3 Blackford Bridge

Given the relative uncertainty in the Agency rating for Blackford Bridge there would appear to be little benefit in undertaking significant additional work at the site solely for the benefit of this Project. Some of the channel dimensions have to be resurveyed due to conflicting data from our survey in 1997 and that provided by external consultants to the Agency as part of the flood defence studies, and it would certainly be useful to collect data from the existing transducer path levels should further events occur.

Accepting this, it must also be noted that to visit the gauging station *en route* to Walcot, or any of the other Agency sites at which SWS are currently undertaking field studies, involves a detour equating to a cost to the Agency of less than £15 per visit. As the gauge belongs to the hydrometric area in which the station is located, we would thus recommend that once the above work has been completed the gauge remains in commission whilst field work is still being carried out at the other sites. The only additional charge to the Agency will be for the travel to the site. Thus, for minimal additional expense to the Agency the Project will gain the potential additional data from the site.

4.4 Walcot

It has already been indicated that the studies at Walcot appear to have been successful with good quality data having been collected from eight different path levels. The transducers are currently located at new levels which, should an event occur, will increase this to ten levels. It is considered that this should be more than sufficient for the purposes of the Project, and that it will not be necessary to undertake any additional routine field data collection at the site.

Discussions with the Project Manager have confirmed this view, but have also raised another issue which can still be usefully addressed at the site. To date trials with reflector systems have only (briefly) been undertaken at Lea Hall. Whilst these were successful, the channel was very small and velocities were low. With the weir at Walcot having a relatively high crest within the channel cross section, deep approach conditions are always guaranteed; minimum depths adjacent to the river bank are of the order of 500-600 mm. As the gauge has always operated well, even at high flows, the site would thus make an ideal one at which to undertake a more rigorous evaluation of a reflector system. The total path length would be greater than 40 metres, making it 7 metres longer than that at Middleton, and would be the longest used for the Project.

It is thus recommended that the field trials at Walcot are extended to include the use of reflector systems. Should the Agency agree to this, it is proposed that the transducer paths are initially located at a height of 0 and 0.3 metres above the weir crest. At these levels the paths will always be covered, data already exist for the -0.1, 0.1, 0.2, 0.4 and 0.5 masd levels, and should the trials be successful additional data will have been provided for the Project. An alternative to this would be to operate the transducers at the same levels as have already been used, say -0.1 and 0.2 masd, to enable direct comparisons to be made.

5 PROPOSED PROGRAMME FOR THE REMAINDER OF THE PROJECT

As this report has confirmed, the field work for the Project is nearing completion and, once the Agency data have been received, the analysis will also be completed. The recorded data has already been processed, and analysis for some of the field sites has been completed and presented in earlier Progress Reports. Given this, it is perhaps useful if attention is turned towards the completion of the Project, and the work that is required to bring this about.

Preliminary discussions have already taken place between the Project Manager and SWS. It has been agreed that as the Project is now running in the 1998/1999 financial year, it is important to ensure that sufficient time is spent in analysing the data and ensuring that as many of the original objectives specified in the PID and which are still outstanding are addressed. It has also been agreed that once the field studies are complete the analysis will be completed and presented to the Project Board in a further Progress Report. We consider that this would then be a suitable time to take stock and assess what the Agency wish to be produced as a result of the Project, ie what information will be presented in the Technical Report and Project Record before work on these documents commences? We have considered a potential timetable for this and, rather than present this as a *fait accompli,* a draft programme has been drawn up and is presented in Table 6.1. We would welcome the views of the Project Board on this.

Table 5.1 Proposed programme detailing the remaining steps needed to complete the Project. The items listed in *italics* may not be required.

Timescale	**Task to be undertaken**	**Output and anticipated completion date**
April - May 1998	Complete remaining field studies, decommission and remove gauges and supply to Agency	Data for final analysis End of May 1998
May 1998	Project Board meeting with contractor to assess field studies and agree on analysis to be undertaken	May 1998
April - June 1998	Complete remaining analysis of all data, possibly including 'revisiting' some of the earlier work to see if subsequent results have changed any of the conclusions.	Progress Report detailing final analysis. Submit to Project Board in July 1998
July/August 1998, (holidays permitting)	Project Board meeting to agree final analysis of data and format & content of Project outputs	Agreed format of Reports, and possible additional requirements for analysis
August 1998	*Complete any analysis identified by Project Board*	*Supply analysis to Project Manager for agreement*
August-September 1998	Prepare draft Technical Report and Project Record	Submit to Project Board in September/October 1998
October 1998	*Project Board meeting to discuss draft reports, if required*	*Agreement on draft reports*
November - December 1998	Prepare final reports and submit to Agency Prepare Project Note (Project Manager)	Final outputs

APPENDIX A

PRELIMINARY ANALYSIS OF DATA COLLECTED AT BLACKFORD BRIDGE FOLLOWING THE JANUARY 1998 EVENT

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26 January 1998

Dear Peter & Alison

Environment Agency R&D Project W6/i646; Calibration of gauging stations using portable ultrasonics

Further to our many recent telephone conversations I have undertaken some **preliminary** analysis of the data from the ultrasonic gauge that was collected earlier this year. A summary of this is attached for your information. I cannot over emphasise the fact that this will almost certainly change once we have managed to check some information, and that the data are drawn from only one real event. However, I understand that the data may be of significant benefit to you in your current studies, and feel that it is better that you have the data as it currently stands.

A summary of the analysis that has been undertaken is as follows:

- For three transducer path levels (0.0, 0.2 and 0.6 masd) the relationship between well level and mean velocity has been plotted. The 0.0 and 0.6 plots use the levels collected by the Agency Telegen/shaft encoder combination, whilst I have had to use the 1408 level data for the 0.2 path (Alison - can you please send me the December 1997 level and flow data on disc - I am unable to read all of the data into the spreadsheet as you suggested).
- Best fit linear and polynomial relationships for these data have then been derived - the order of the polynomial was determined on a trial and error basis, with the most realistic (rather than best fit R^2 value) relationship being used.
- These relationships were then used to derive stage-discharge relationships for each of the three transducer paths, dividing the river into four horizontal 'slices'.
- The different 'slice' components have then been summed to produce the total discharge, and this has been plotted in both graphical and tabular format for comparison with the Agency and HR stage-Q relationships.

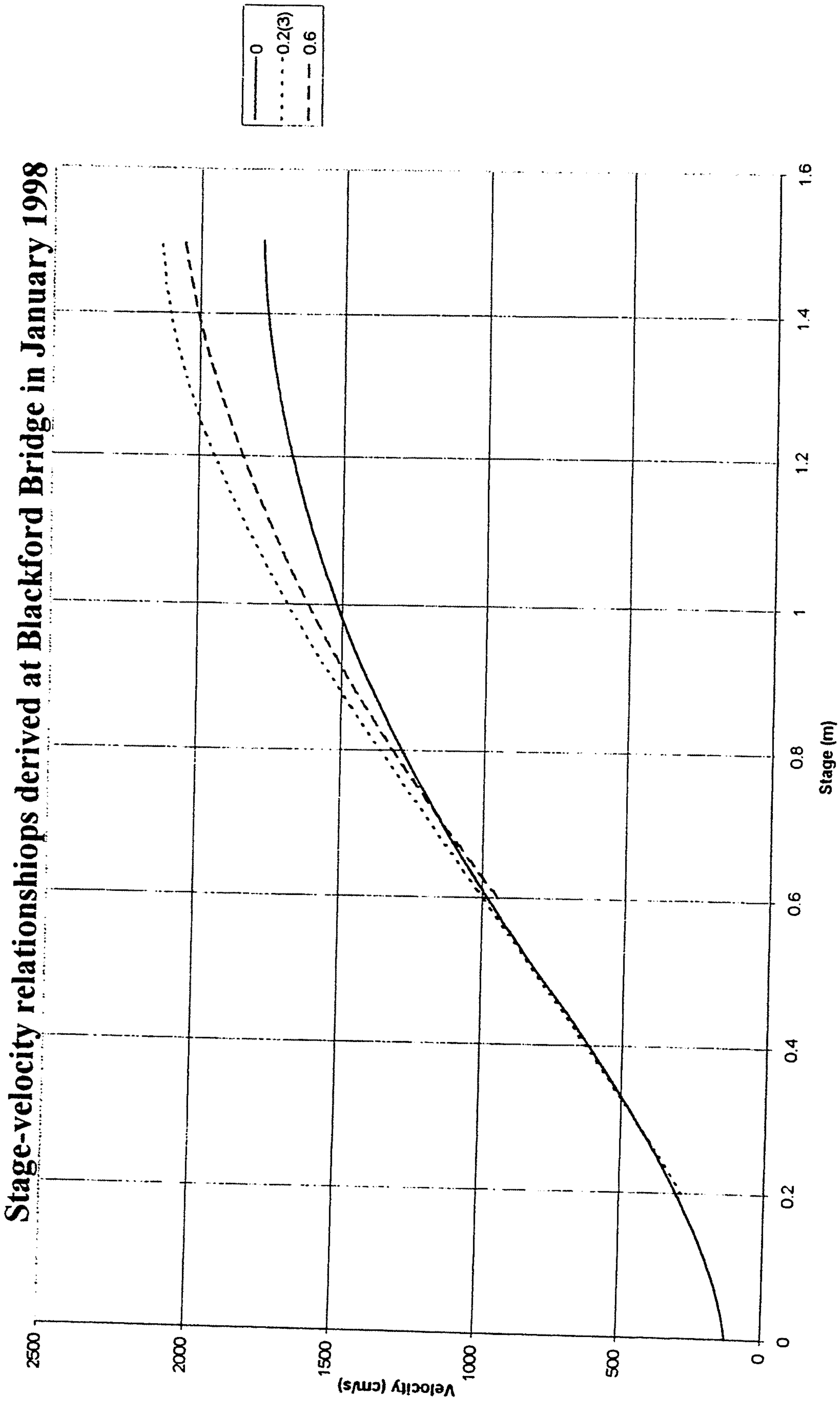
Some points that I would like to make:

1. We need to check the channel width between the two transducer racks - I have it recorded as 16.45 metres, but HR indicate the crest width is 23 metres. Accepting that the crest is not straight, and that the river does 'fan out' towards the weir, I have none-the-less increased the channel width to 17.5 metres.
2. I feel that the linear and polynomial relationships indicate the two extremes of the potential relationship - the most realistic relationship is likely to be somewhere between the two but as I only have data from one event I cannot verify this at present.
3. Both methods will underestimate the true river flow due to the recorded level being lower than the true level above the ultrasonic paths. At a 'true' stage of just under 1 metre this difference was observed to be c. 65mm, accounting for between 2 and 3 additional cumecs.
4. The only way I can see to overcome this 'unknown', and remove some of the systematic error that is endemic with the current methodolgy, is to deploy a level recorder at the staff (or immediately upstream) and compare u/s levels to well levels. Once a relationship has been confirmed this can then be used to derive a new rating based on current metered flows and the well levels which are actually used to derive the processed flows.
5. The bad news is that this will make the differences between the Agency rating and that produced by myself and HR even greater! This may suggest that there is another source of systematic error. I have given this considerable thought and can only say that, without wishing to cast doubt on the hydrometric staff of the Area (past and present), this systematic error **may** be due to the current meter gaugings. I assume that bridge gaugings are carried out under high flows - given that the 1408 recorded **mean** velocities of between 1.5 and 2 m/s the peak velocities in the centre/outside edge of the channel are likely to be much higher. This is likely to require a very heavy sinker weight which I assume is not possible because of manual handling/safety/real world practicalities. Consequently, another systematic error may be introduced by the angular nature of the suspension cable - the only way to verify this is by cableway gauging so good luck with the planners Alison! Further problems may arise due to the very deep channel on the north bank - more than a metre deeper than a short distance downstream.

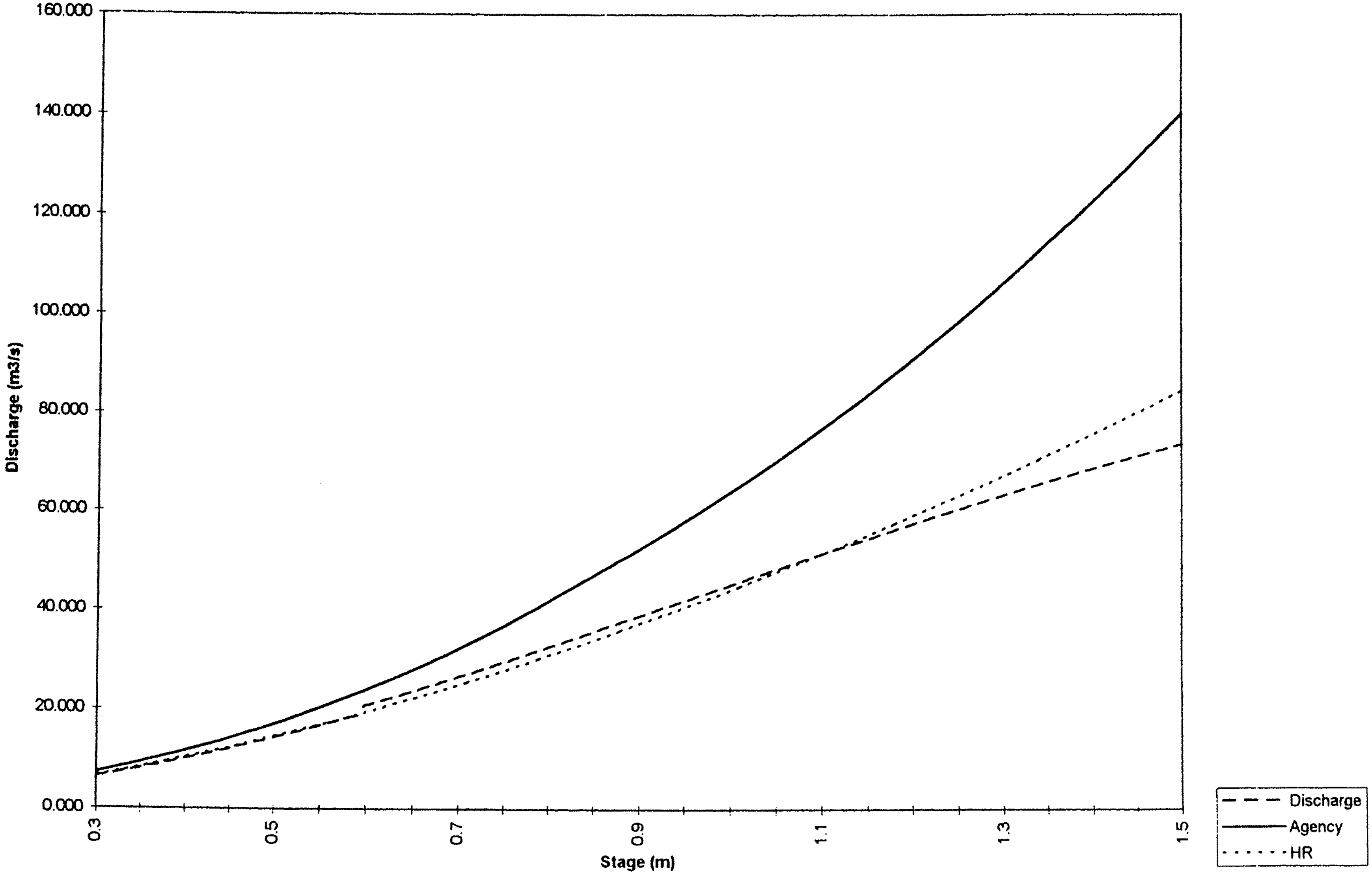
The bottom line is that, on the basis of the limited data which has been collected so far, I consider that the HR rating is more likely to reflect the true picture than the one that has been used by the Agency. Subsequent 'tweakings' to the analysis are unlikely to change this fundamental point, but I will keep you both advised. In the meantime, keep your fingers crossed for more events! Feedback will be well received.

Yours sincerely

A M Bennett
Enc.


Stage-velocity relationshiops derived at Blackford Bridge in January 1998

Blackford Bridge rating based on non-linear extrapolation of ultrasonic data; assumed channel width 17.5 metres



Stage	Discharge (non-linear)	Discharge (Linear)	Agency	HR
0.3	6.485	6.649	7.345	6.595
0.31	6.799	6.967	7.725	6.936
0.32	7.122	7.291	8.115	7.284
0.33	7.454	7.621	8.517	7.639
0.34	7.794	7.958	8.931	8.000
0.35	8.143	8.301	9.356	8.367
0.36	8.499	8.651	9.792	8.741
0.37	8.864	9.007	10.241	9.121
0.38	9.237	9.369	10.701	9.507
0.39	9.617	9.737	11.172	9.899
0.4	10.006	10.112	11.656	10.298
0.41	10.402	10.493	12.152	10.703
0.42	10.806	10.881	12.660	11.114
0.43	11.218	11.275	13.180	11.530
0.44	11.637	11.675	13.713	11.953
0.45	12.077	12.082	14.258	12.381
0.46	12.529	12.495	14.815	12.816
0.47	12.985	12.914	15.385	13.256
0.48	13.446	13.340	15.967	13.702
0.49	13.912	13.772	16.563	14.154
0.5	14.382	14.211	17.171	14.611
0.51	14.858	14.655	17.791	15.074
0.52	15.338	15.107	18.425	15.543
0.53	15.822	15.564	19.072	16.017
0.54	16.312	16.028	19.732	16.496
0.55	16.806	16.498	20.405	16.981
0.56	17.305	16.975	21.091	17.472
0.57	17.808	17.458	21.790	17.968
0.58	18.316	17.947	22.503	18.469
0.59	18.829	18.443	23.230	18.976
0.6	20.814	20.612	23.970	19.488
0.61	21.368	21.141	24.723	20.005
0.62	21.926	21.676	25.490	20.528
0.63	22.489	22.217	26.271	21.056
0.64	23.055	22.764	27.066	21.589
0.65	23.625	23.316	27.875	22.127
0.66	24.198	23.874	28.697	22.670
0.67	24.775	24.439	29.534	23.218
0.68	25.356	25.009	30.384	23.772
0.69	25.940	25.584	31.249	24.330
0.7	26.527	26.166	32.128	24.894
0.71	27.117	26.753	33.022	25.462
0.72	27.710	27.346	33.929	26.036
0.73	28.306	27.945	34.852	26.614
0.74	28.904	28.550	35.788	27.198
0.75	29.505	29.161	36.739	27.786
0.76	30.109	29.777	37.705	28.379
0.77	30.715	30.400	38.686	28.977
0.78	31.323	31.028	39.681	29.580

Stage	Discharge (non-linear)	Discharge (Linear)	Agency	HR
0.79	31.934	31.661	40.691	30.188
0.8	32.546	32.301	41.716	30.800
0.81	33.161	32.947	42.756	31.417
0.82	33.777	33.598	43.811	32.039
0.83	34.395	34.255	44.810	32.666
0.84	35.014	34.918	45.833	33.297
0.85	35.635	35.587	46.868	33.933
0.86	36.257	36.261	47.914	34.574
0.87	36.881	36.942	48.973	35.220
0.88	37.505	37.628	50.044	35.870
0.89	38.131	38.320	51.127	36.524
0.9	38.757	39.018	52.222	37.183
0.91	39.384	39.721	53.329	37.847
0.92	40.012	40.431	54.448	38.516
0.93	40.640	41.146	55.579	39.189
0.94	41.269	41.867	56.722	39.866
0.95	41.898	42.594	57.878	40.548
0.96	42.528	43.327	59.045	41.234
0.97	43.157	44.065	60.225	41.925
0.98	43.786	44.810	61.416	42.620
0.99	44.415	45.560	62.620	43.320
1	45.044	46.316	63.837	44.024
1.01	45.673	47.077	65.065	44.733
1.02	46.301	47.845	66.305	45.446
1.03	46.928	48.618	67.558	46.163
1.04	47.554	49.398	68.823	46.885
1.05	48.180	50.183	70.100	47.611
1.06	48.805	50.974	71.389	48.341
1.07	49.429	51.770	72.691	49.076
1.08	50.051	52.573	74.005	49.815
1.09	50.672	53.381	75.331	50.558
1.1	51.292	54.195	76.669	51.306
1.11	51.910	55.015	78.020	52.058
1.12	52.527	55.841	79.383	52.814
1.13	53.142	56.672	80.758	53.574
1.14	53.754	57.509	82.145	54.339
1.15	54.365	58.353	83.545	55.107
1.16	54.974	59.202	84.957	55.880
1.17	55.581	60.056	86.381	56.657
1.18	56.185	60.917	87.818	57.438
1.19	56.786	61.783	89.267	58.224
1.2	57.386	62.656	90.729	59.013
1.21	57.982	63.534	92.202	59.807
1.22	58.576	64.417	93.688	60.605
1.23	59.166	65.307	95.187	61.406
1.24	59.754	66.203	96.698	62.212
1.25	60.338	67.104	98.221	63.022
1.26	60.920	68.011	99.757	63.836
1.27	61.497	68.924	101.305	64.655
1.28	62.072	69.843	102.865	65.477

Stage	Discharge (non-linear)	Discharge (Linear)	Agency	HR
1.29	62.642	70.767	104.438	66.303
1.3	63.209	71.697	106.023	67.133
1.31	63.773	72.634	107.621	67.967
1.32	64.332	73.576	109.231	68.806
1.33	64.887	74.523	110.854	69.648
1.34	65.438	75.477	112.489	70.494
1.35	65.984	76.436	114.136	71.344
1.36	66.526	77.402	115.796	72.198
1.37	67.064	78.373	117.469	73.056
1.38	67.597	79.349	119.154	73.918
1.39	68.125	80.332	120.851	74.784
1.4	68.648	81.321	122.561	75.654
1.41	69.167	82.315	124.283	76.528
1.42	69.680	83.315	126.018	77.406
1.43	70.188	84.321	127.766	78.287
1.44	70.690	85.333	129.526	79.172
1.45	71.187	86.350	131.298	80.062
1.46	71.679	87.374	133.083	80.955
1.47	72.165	88.403	134.881	81.852
1.48	72.645	89.438	136.691	82.753
1.49	73.119	90.479	138.514	83.657
1.5	73.587	91.525	140.349	84.566

APPENDIX B

EXTRACT FROM A FLAT V WEIRS PROGRESS REPORT DESCRIBING SOME OF THE FINDINGS FROM AN ANALYSIS OF THE DATA COLLECTED AT WALCOT GAUGING STATION IN DECEMBER 1996

Note that the extract is from a section in the Report which dealt specifically with the issue of uncertainties in flow derivation. Figure 6.2 illustrates the different relationships observed during the two events, whilst Figure 6.4 presents velocities derived by a number of means.

6.3.1 Case study: Walcot on the River Tern

This site has been rated by current meter over a number of years. The crest tapping has recently been reinstated, together with an automated flushing system, and some results are now available to allow calculation of flow using the weir formula and appropriate reduction factors in the non-modular range. In addition, ultrasonic velocity measurements from a twin path gauge are being made at this site as part of another R&D project and these have also been used in the analysis. The catchment is fed from a groundwater source and thus responds slowly to any change in hydrological conditions. This results in any 'significant' events taking place over many days, potentially allowing a detailed analysis to be undertaken.

Stage and crest values at 15 minute intervals for the month of December 1996 were used to compare the different methods of calculating flow and assess how various assumptions affect the result. Stage discharge calibration requires that the effective control is stable so that the relationship between stage and discharge is predictable. This is certainly the case in the modular range but only applies to the non-modular range if the tail water control is stable as it is this that becomes the effective control in the non-modular state.

Current meter measurements have been made over a wide range of stage, 0.3 to 2.4 m, so the December event, which reached 1.4 m, was well within the range of the stage-discharge calibration. Flows were computed for each stage value using

- the stage discharge rating
- the modular weir formula with no allowance for non-modularity and
- the weir formula with reduction factors applied to deal with the non-modular state.

These are plotted for comparison, together with the current meter gaugings at this site in Figure 6.1.

From this it can be seen that up to a value of about 0.6 m stage there is good agreement between each method of computation. However, above this level the relationships produced by the different methods begin to diverge. The first point to discuss is the substantial difference between the stage-discharge rating and the corrected weir formula approach in the non-modular range. Whilst they would appear to converge at higher levels, there is considerable discrepancy in the derived flows (typically 25-35%) between a stage of 0.7 and 1.2 metres. Which, if any, of the two relationships is correct? Available current meter measurements show few values to support the weir formula results. However, they also display considerable scatter, especially around 0.9 m stage, which is close to where the stage-discharge relationship departs from the weir equation. This scatter suggests that the rating curve is also uncertain in this region and relies heavily on the mass of gaugings at higher and lower stage values to carry the calibration through. It would also appear that the point of departure from the weir equation has been controlled when setting the stage-discharge relationship, possibly to coincide with the perceived modular limit. This strongly suggests that the tailwater-flow relationship is not stable and that the modular limit does not always occur at the same stage value.

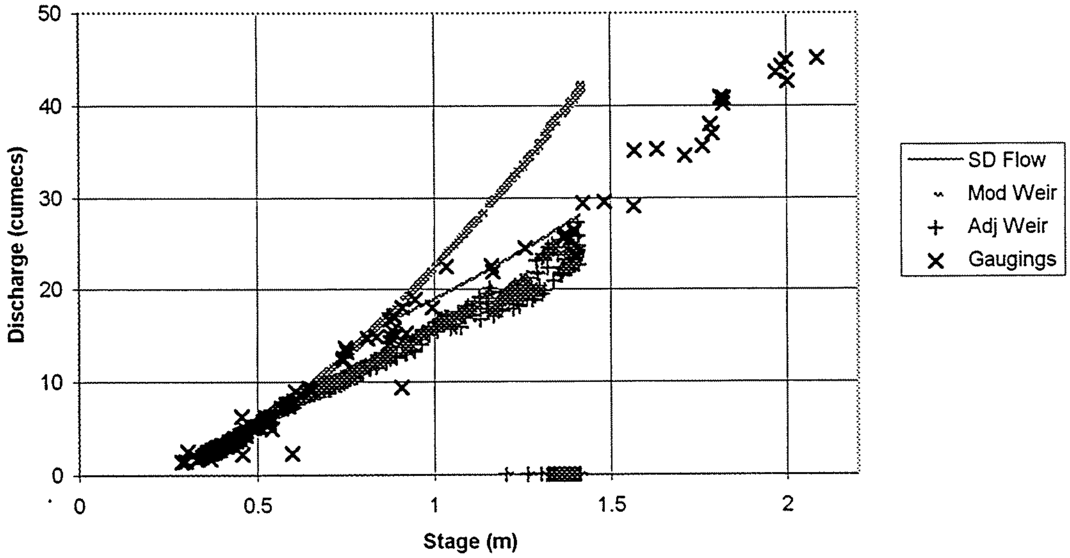


Figure 6.1 **Stage-discharge relationships derived by three different methods, plotted with current meter gaugings for Walcot gauging station.** Note that indeterminable values are shown as zero - in reality they would be treated as missing data. The data have been derived from the event in December 1996. 'Mod weir' is the extrapolated modular weir equation, 'Adj Weir' is the weir equation corrected with crest tapping data, and 'SD Flow' are the flows derived from the current stage discharge relationship.

It was noted when plotting stage against discharge from the weir formula that a higher discharge was being obtained for the same stage during the recession limb compared with the rising limb of the event. Loop stage-discharge relationships often occur when the tailwater levels remain elevated during the recession phase, the reduced channel capacity resulting in a reduced flow for a given stage. However, in this case the crest tapping data suggest that the reverse situation was occurring. It was also noted that this effect was progressive. The first, smaller peak earlier in the month showed the effect, with the computed non-modular flow at the end of the event higher than at the start for the same stage. However, this higher stage - flow relationship continued to apply at the initial phase of the second peak, and was then followed by a further increase in flow for the same stage during the recession limb of the second event.

Only the crest tapping is capable of influencing the computation to produce this effect. If it is real then lower tailwater levels occurred, producing lower crest pressure readings during the falling limb of the event compared with rising stage values. Unless a fault can be found in the crest tapping system which can explain lower pressure during a falling stage compared with a rising stage, (and the observation that the new relationship applies during the rising limb of the second event would suggest that this is unlikely), leads to the conclusion that it is real and supported by the observation that it appeared to be cumulative from one event to another during December. The relationship between hpe/He and stage is shown in Figure 6.2 and the progressive nature of the change can be seen. This suggests that a real change took place that altered the tailwater level/flow relationship. It is speculated that it would be consistent with accumulated material and weed being scoured from the channel. Personal observations from the site are that the remains of the weed which had grown in the channel was flattened during the month, supporting this speculation.

While the above discussion supports the view that the modular limit is not constant with respect to upstream stage at this site, there is still a considerable gap between the flows produced by the two methods. Initial close agreement is followed by a fairly rapid increase in the difference between the two results, before converging again at higher flows. These are shown in Figure 6.3.

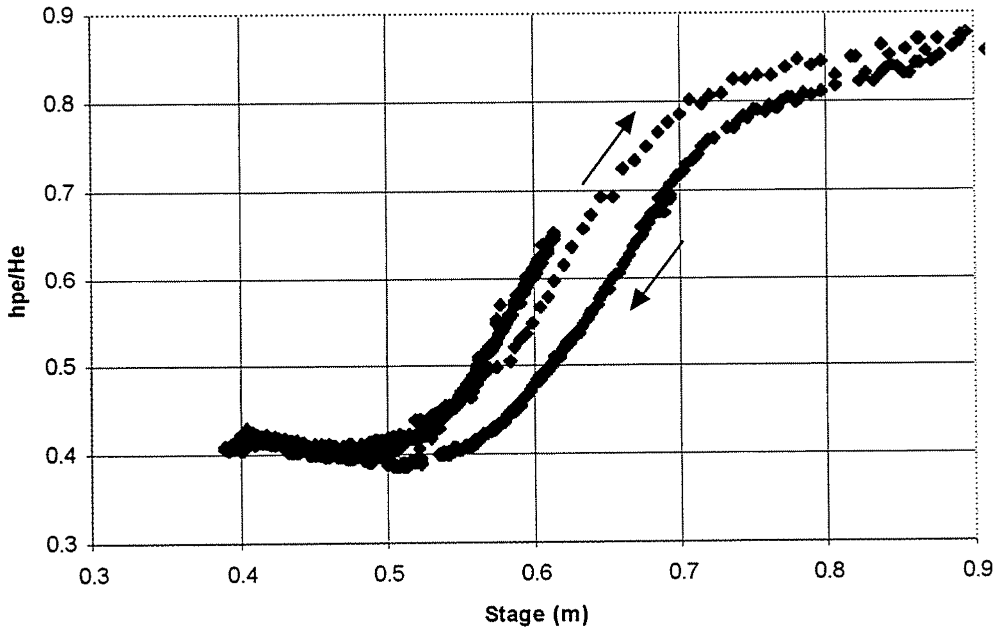


Figure 6.2 H_{pe}/H_e plotted against stage for the December 1996 event at Walcot gauging station. The arrows indicate values obtained on the rising and falling limbs of the hydrograph.

Velocity readings from the ultrasonic gauge potentially provide an insight into the 'true' flows during the event. Although the equipment was not installed for this purpose, and it is known that the configuration of the gauge during the event is likely to produce systematic errors in the derivation of flow, it provides a totally independent measure of velocity that can be compared with that derived from the other two methods. For this purpose, computed discharge was divided by the cross sectional area A = b*(h+P).

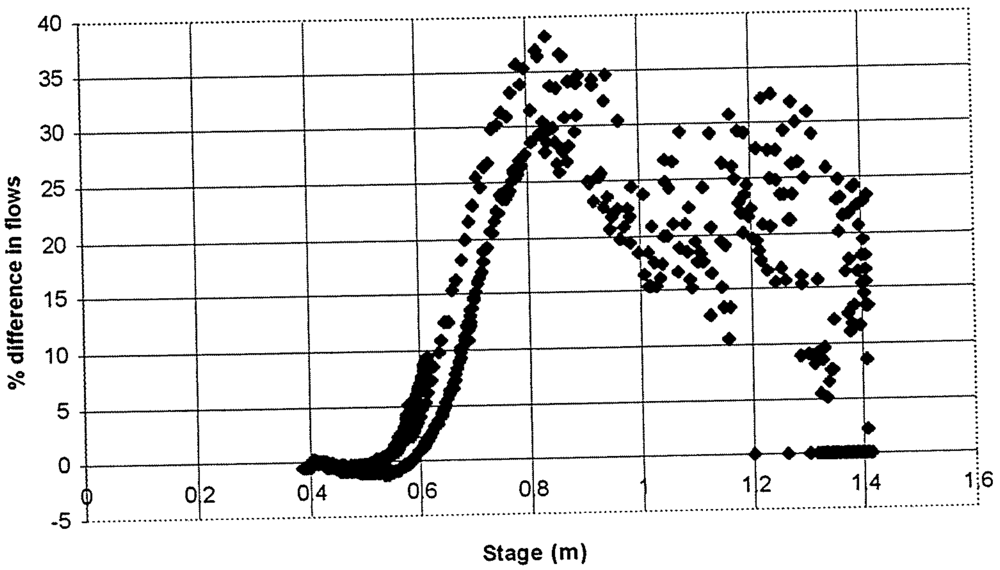


Figure 6.3 **Percentage difference between flows derived by the stage discharge and corrected weir formula methods plotted against stage for the December 1996 event at Walcot gauging station.** Note that the cluster of points with zero difference between 1.2 and 1.42 metres stage are a function of the iterations used to derive the data for the plot - they are produced from the same 'zero' data plotted in Figure 6.1 that would, in reality, be returned as missing data.

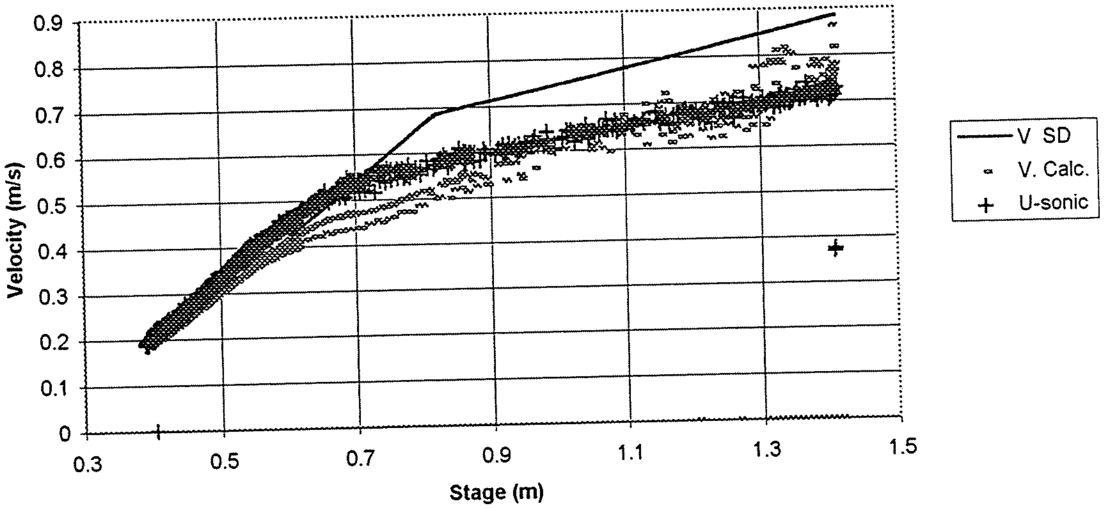


Figure 6.4 **Velocity readings derived from the stage discharge (V SD), corrected weir formula (V Calc) and twin path ultrasonic gauge (U-sonic) plotted against stage for the December 1996 event at Walcot gauging station.**

Velocities from the three sources are compared in Figure 6.4. In this the separate rising and falling tracks can be clearly seen in the velocities derived from the weir formula and the velocities recorded by the ultrasonic gauge, although the difference is not so great in the latter. This also supports the view that the changes are real. The ultrasonic device would appear to over-estimate velocity in the modular range compared with the other two methods. However, it is more in line, generally, with the weir equation until higher stages are reached when it is inclined to under-estimate mean velocity. This can be explained by the fact that the velocity measurements used for this analysis are only derived from a single path. Thus, whilst at a low stage the path will be closer to the water surface, and thus over-estimate the true velocity, at higher levels the path was below the level of the 'mean velocity' and thus under-estimates the mean channel velocity.

The conclusion from this is that the results produced by the weir equation are credible and reflect true conditions within the river during the December event. However, whilst flows in the modular range do not appear to be in doubt there are still some limitations to the use of the method in the non-modular range. As flows leave the modular range the calculation of the reduction factor becomes very important. For values of hpe/He up to 0.85 the computed values of Fv are reasonably stable. Above this level small fluctuations in both head measurements are amplified in the calculation of Fv, as shown in Figure 6.5. The equation for Fv is such that Fv rapidly approaches 0 as $(hpe/He)^{1.5}$ approaches 0.9085 (hpe/He = 0.938, at a stage of approximately 1.2 metres). When the fluctuations in measured head produce values greater than this, Fv cannot be resolved. This is illustrated in Figure 6.6 where the flow has been returned as 0 when this has occurred.

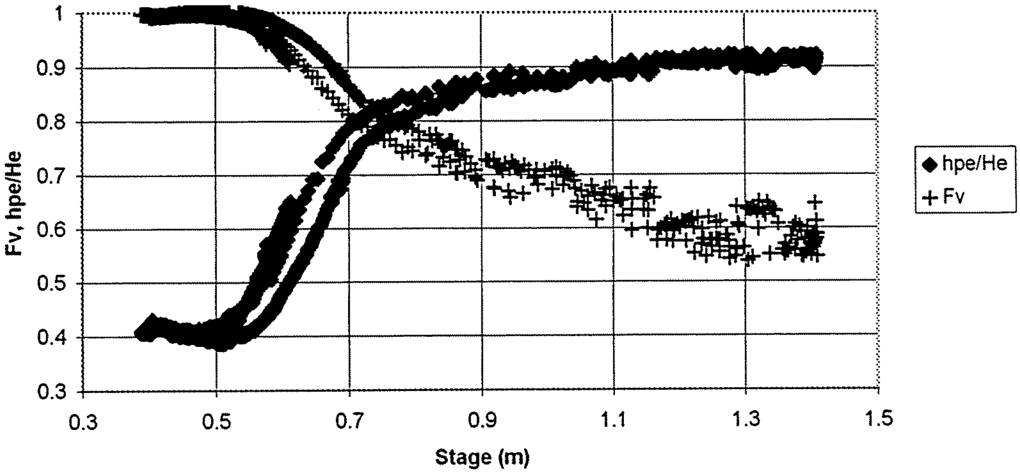


Figure 6.5 H_{pe}/H_e and F_v plotted against stage for the December 1996 event at Walcot gauging station. It can be clearly seen that as H_{pe}/H_e approaches a value of 0.94 (stage 1.2 m) the range in F_v significantly increases.

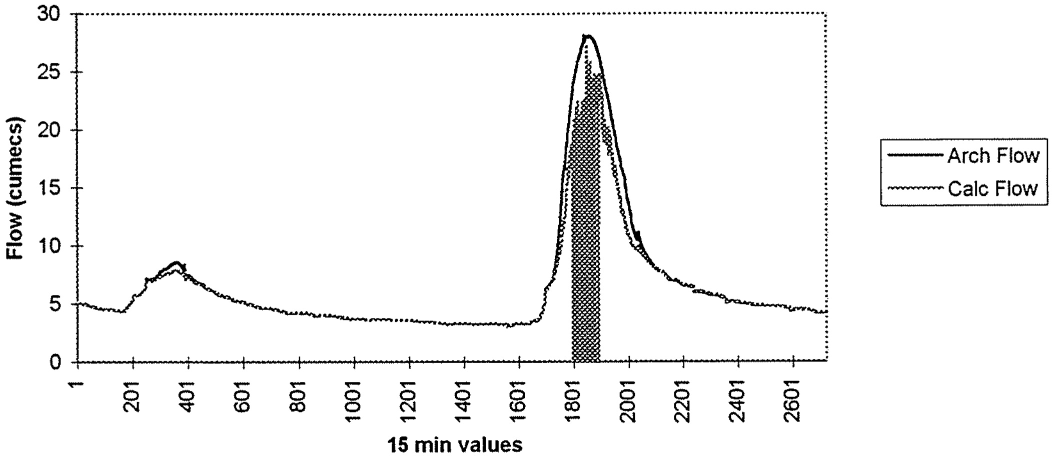


Figure 6.6 **Plot to show the effect of being unable to resolve F_v when correcting the weir formula for the December 1996 event at Walcot gauging station. Arch Flow is that produced by the stage discharge relationship, Calc Flow is the corrected weir formula.**

It must be remembered that the iteration used in both the Standard and this analysis uses a single, empirical relationship to derive the correction factor for a given hpe/He ratio. Reference to the original work from which the Standard was developed (White, 1981) reveals that instead of producing a single curve, the different plots from which this relationship is drawn form an envelope. At its widest, this envelope has a correction factor range of 0.1 for a given ratio, with the majority of the range being less than 0.05. This results in a potential uncertainty of between 4 and 16% in the derived flow, equating to an error range of between 2 and 8% about the 'mid-curve' in the envelope. Some of this uncertainty arises from the fact that different channel geometries produce different relationships, to which there is added an element of random error. It can thus be seen that if the channel in which a weir is located does not have the same approach conditions as those of the mid-line in the original envelope curve, there will be a systematic error introduced into the flow correction calculations.

One final observation is that whilst the crest tapping at Walcot has had a flushing system recently installed, and that this has resulted in data collection now being possible, the system has itself resulted in additional problems. These arise due to the pumped water within the tapping acting as an effective hydraulic press on the crest tapping plate, resulting in the plate lifting every time the system operates (at present, every eight hours). Whilst these data can be edited to remove the 'step' that this produces, the observation does confirm that further work is required to overcome the problem.

6.3.2 Conclusions

Within the limitations of what can be deduced from analysis of data from a single station for a single, twin peak event, there are clearly a number of points for discussion. The effective range of the weir at Walcot is limited to an upper stage value of about 1.2 m. Beyond this the correction factor is unreliable and the weir appears to drown completely at about 1.4 m. Up to 1.2 m, it would appear that the crest tappings produce a better estimate of flow than the stage discharge rating currently in use. At stages above 1.2 m the stage-discharge calibration is more stable and, above 1.3 m, it is the only method which remains consistently effective, with the dependency of the crest tapping method on Fv causing the iteration to fail. Whilst this problem may be overcome by returning a predetermined value once this happens, the stage discharge rating is the only method which continues to progressively correct for non-modular conditions above this point.

It is believed that the tailwater level is affected by a variable control which introduces inconsistencies into the stage discharge calibration data set. It would appear that the current stage discharge equation has been influenced by measurements made when the modular limit was at a higher stage value than during the December event. It is difficult to draw general conclusions from one event at one site but, if similar features are found elsewhere, we would suggest that:

- If the modular limit does not occur consistently at the same value of upstream stage, then in-situ current meter calibration to the upstream stage is unlikely to be better than a well maintained crest tapping.
- Over the range in stage that coincides with the lower and upper extents of the non-modular limit the stage discharge relationship produces results that differ from the calculated flow by as much as 35%.
- If the range of flow extends beyond the useful range of the weir, i.e. hpe/He > 0.93, an alternative method of flow measurement to the weir equation is required to extend the effective range of the structure.
- The weir formula must not be used unadjusted outside the modular range without verification by current meter gauging. The error in the peak flow would have been greater than 80% for the event studied, and this was itself only a minor event.

Finally, it must be noted that the Midlands Region are aware that the existing rating does overestimate flows at the transition between modular and non-modular conditions. As previously explained, this is partly due to the way in which the curve was fitted. Corrective action in producing a short third section to the rating at this point would reduce the uncertainty. Despite these problems, the Walcot station is well equipped to enable the Region to assess the scale of these uncertainties; this is reflected in the amount of analysis that has been possible from data collected at the station.

PROGRESS REPORT 8 (20/10/98)

1 INTRODUCTION

This Progress Report summarises the progress made on the Environment Agency R&D Project W6/i646 (formerly NRA R&D Project B01 (95) 01), Calibration of Gauging Stations Using Portable Ultrasonics, between March and October 1998. It is anticipated that this will be the last of the Progress Reports, with subsequent documents forming the Project deliverables. This report will:

1. Summarise the work that has been completed at each site, and the data that have been collected.
2. Outline the work that remains to be done to complete the Project.
3. Suggest a draft format for the Technical Report.

2 LIAISON WITH THE AGENCY

The majority of the liaison with the Agency has been of a routine nature, and relates to the three field sites that have been used during the period. 'Standard' data have been provided for all three sites by the relevant Agency offices, enabling the analysis of the data collected at the three sites to be started.

A meeting was held at Middleton in Teesdale gauging station to discuss the work that has been undertaken at the site. Even though the gauges have only worked on an intermittent basis at the site, the Region has recognised the potential of using the gauges at other, more suitable, sites. During the meeting the issue of the effect of suspended sediment load on gauge performance was discussed, following which we have been provided with some quantitative data by Paul Wass of the Newcastle office. We are unable to reproduce this information at present as it was collected by Paul when working for the Institute of Hydrology; Paul has requested that we be given permission to use the data for the Project.

The only other significant liaison with the Agency that relates to this project has been with the North Area of the North West Region. They have also decided to use ultrasonic gauges at a number of sites to quantify high flows, and have sought advice and assistance with this. Hopefully their gauges will be installed and working before the final Reports are produced as both installations will be using the transducers (500 kHz and 1 MHz) over longer path lengths than those used during the Project.

3 WORK COMPLETED DURING THE PERIOD

3.1 Middleton in Teesdale

Of the three field sites that have been used the results from Middleton are the most disappointing. The previous Report (W6/i646/7) described the difficulties that had previously been encountered in getting the transducer paths to work at medium - high flows. Peek kindly agreed to loan the Project two 250 kHz transducers, and these were installed on the lower path. Despite extensive efforts it has not been possible to get these to work at all; they are firing, but the gauge is unable to record any returned signals. We are currently liaising with Peek to explore yet more ways of trying to get these to work but, if we continue to be unsuccessful, we suggest that the gauge is removed from the site after the next two visits. We would appreciate confirmation from the Project Board that this is acceptable.

3.2 Blackford Bridge

The gauge at Blackford Bridge was removed during July before vandals damaged the equipment during the school holidays. The use of the short link galvanised chain was a great success, and all cables were intact when the gauge was removed. The equipment has been cleaned and tidied up, and will be returned to the Sale office shortly.

Whilst removing the equipment the opportunity was also taken to re-survey the channel, as there had been doubts about the 'true' channel width due to differences between SWS and HR data. The information collected during the survey has been used in the site report, which is nearing completion.

3.3 Walcot

A number of visits have been made to Walcot, and the gauge has continued to perform well throughout the period covered by this Report. Minor problems were encountered due to extensive weed growth in the channel, with the weed extending over the actual weir crest on occasion. It was always possible to get the gauge working again after spending a limited amount of time (generally less than an hour) clearing the weed along the line of the transducer paths.

One significant piece of work that was completed at the site was the evaluation of reflector systems, undertaken in early September. A single reflector was used, made of 6 mm steel plate and measuring 300 mm by 1200 mm. The reflector was placed against the far transducer tower, and an additional set of upstream transducers was installed on the near bank. The system worked at the first attempt, despite the presence of weed in the channel, although it was noted that the typical count of successfully received sound pulses was approximately half that of the single path installation. Full details of the trials will be included in the Walcot Site Report.

4 RECOMMENDATIONS FOR WORK STILL TO BE UNDERTAKEN

4.1 Field studies

It can be seen from Section 4 that the majority of the field work has been completed at the Agency gauging stations. The only 'missing' item is positive results from Middleton. If these are not forthcoming after the next two visits then we shall remove the equipment, subject to the approval of the Project Board.

The gauge at Walcot has provided sufficient data for the purpose of this Project; as a result we shall only be charging for one further visit to remove the equipment. However, rather than remove this immediately, we would prefer that the gauge be left *in situ* until the end of December as it is providing useful data for the Agency R&D project looking at non-modular flows over flat V weirs. The site is presently instrumented with upstream, crest and downstream wells, together with the ultrasonic gauge and a doppler shift gauge mounted on the wingwall. The data from the 1408 are being used to assist with the development of a method for deriving non-modular flows; in particular they are being used to assess the onset of non-modular conditions, together with allowing the doppler shift gauge performance to be evaluated. **We would be grateful if the Project Board would confirm that it is acceptable to leave the gauge installed at Walcot until January 1999.**

4.2 Analysis of data

The near completion of the field studies has allowed work on the Site Reports to commence. The Blackford Bridge Report will be completed in early November, following which the Middleton Report should be ready by the end of the month.

The Walcot Report is likely to take somewhat longer to complete, due to two reasons. Firstly, the quantity of data that have been collected means that there is considerably more analysis to be undertaken, although the majority of the Report will draw from specific events. Secondly, the existence of the crest tapping and tailwater level data at the site means that there is considerable scope for deriving non-modular flows by a number of methods. We shall be liaising with the Agency as the corrected data are derived, for both this and the flat V weir projects; consequently, in addition to the additional analysis there is likely to be a delay caused by the need for both SWS and the Agency to consider the processed data before it can be used as the baseline to which the 1408 data are compared.

Once the Site Reports have been completed, likely to be mid- December, the draft Technical Report is likely to follow shortly afterwards. Realistically, it should be with the Project Board in early January.

5 PROPOSED STRUCTURE FOR THE TECHNICAL REPORT

Work has already started on drafting some of the sections of the Technical Report, although it will not be possible to complete this until after the remaining Site Reports have been finished. Whilst some of the Report sections are relatively simple to decide and define, there is considerable scope for different structures depending on where specific information is placed. For example, should the results of the field work be contained in the Technical Report itself, an appendix, or in the Project Record? Considerable thought has been given to this issue, and the following structure is proposed. It is based on the premise that the typical reader will have access to the full Report and Appendices, but will have to search further to obtain the Project Record.

EXECUTIVE SUMMARY
Single page abstract summarising the contents of the Report.

1 INTRODUCTION
Including :

- Background to the Project;
- Aims and objectives of the Project;
- Organisational details;
- Outline of the structure of the Report itself.

2 TECHNICAL BACKGROUND

A literature review to include:

- The underlying principles of the time-of-flight gauges;
- Development of the method in the UK;
- Use of the approach in a wider context (still awaiting details from the US via the WWW).

Details of the Peek 1408 gauges used for the Project.

3 FIELD STUDIES

A brief summary of the sites used for the Project, the reasons why these were used, and an overview of the results obtained at each site. More detail will be provided for the approaches that were used for the field work, together with details of the mounting systems etc.

This Section is likely to be one of the most difficult to write; it will have to provide the reader with sufficient detail to enable them to read the rest of the Report, but at the same time should avoid too much detail as this will only serve to distract the reader.

It is suggested that this Section is accompanied by an Appendix to the main Report, which will contain summary details for each of the sites. This might be a two page summary of each of the Site Reports, providing an insight into the nature of each of the gauging stations (including both a diagram and photographic record), the work that was undertaken at the site, any problems that were encountered and a list of the objectives that were met.

The Project Record will contain full details of the individual Site Reports, together with the data from the individual events that were used for the analysis. It is envisaged that full data-sets will be provided on a separate CD-ROM for reference by any interested party.

4 USING THE GAUGE AS A TWIN PATH SYSTEM

By providing examples from the Site Reports this section will evaluate the use of the gauge with the transducers deployed at a fixed level throughout the entire survey period. It will include:

- Typical performance of the gauges, illustrated by examples;
- An assessment of the uncertainties associated with this method of deployment;
- Limitations of the approach;
- The use of data collected from multi-path gauges to try and identify an ‘optimum’ set of levels for the two paths;
- Typical operational costs of this approach.

5 USING THE GAUGE TO REPLICATE A MULTI-PATH INSTRUMENT

This section will follow a similar structure to Section 4, but will address the use of the gauge at more than two levels during the survey period.

6 MISCELLANEOUS FINDINGS & STUDIES (alternative name for this section still sought - suggestions welcome!)

A number of 'one-off' studies have been included in the project, including the use of reflectors, non-horizontal transducer paths, multi-path deployment during a specific event etc. Rather than clutter up Sections 4 and 5 with this information, it is suggested that a more useful approach would be to place these results in a separate Section.

7 CONCLUSIONS AND RECOMMENDATIONS FOR IMPLEMENTATION

It is too early at this stage to provide full details of this Section as it will depend on the analysis that is still underway. However, it is envisaged that a set of guidelines for each of the two approaches will be proposed, together with recommendations for actually installing the equipment.

Finally, any areas for further will be identified, together with an overview of recent advances that may improve gauge performance at 'problem' sites.

We would appreciate any feedback from the Project Board on this proposed structure.

9 BLACKFORD BRIDGE SITE REPORT

1 INTRODUCTION

Blackford Bridge gauging station is located on the River Roch to the north of Manchester, and is operated by the South Area of North West Region. The Roch catchment at this point is some 186 km^2 and is highly urbanised, particularly in the lower half which flows through Rochdale. Consequently, the river displays a diurnal pattern in levels during stable periods of low flows. The river usually responds rapidly to rainfall events on account of the high degree of urbanisation and the fact that the upper catchment is located on the western side of the Pennines.

The station control is a broad-crested mill-type weir, which is curved (upstream) in plan. Prior to 1976 the rating was based on a theoretical formula which was known to be of dubious quality, not least because of the poor condition of the weir crest. A current meter rating is currently used at the site, which is considered to be more stable but still far from perfect. The station rating has recently been the subject of considerable study by external consultants, including Hydraulics Research, due to the development of a flood prevention scheme within the catchment.

The site was chosen as a suitable study site for a number of reasons. These include:

- The station is an example of the type which a number of Regions have expressed a desire to calibrate by using portable ultrasonic gauges. It was thus considered to be of benefit to evaluate the suitability of the equipment to this type of site.
- The South Area were able to provide a gauge for use at the site, resulting in a total of three gauges being available for the Project. As the Project had had to be extended due to the exceptionally dry winter of 1995/96, this meant that the chances of suitable high flow events occurring was significantly increased, thus increasing the probability that the Project as a whole would meet its objectives.
- The station was known to be a 'problem' site, namely it is very difficult to obtain high flow gauging data at the site as this required bridge gauging from a considerable height. Would the equipment provide a viable alternative to this?
- The channel upstream of the weir was both wide and deep, extending the range of installation conditions used for the Project.
- The mill weir was very high (estimated to be greater than 1.5 metres), ensuring that non-modular flows would not become an issue.
- It would not be possible to use a cableway to get the cables across the river, due to the lack of a cableway and the high vandal risk of the site. It would thus be necessary to evaluate an alternative method of deploying the gauge.
- Finally, it would be possible to visit the gauge whilst *en route* to other sites being used for the Project. Thus, the addition of a third gauge to the Project would be achieved in the most cost effective manner.

2 GAUGE INSTALLATION

The gauge was installed in April 1997, and removed in August 1998. The configuration of the installation is shown in Figure 2.1. It can be seen from this that the site is located on a long but gentle bend in the river, which caused some difficulty when establishing the angle between the direction of flow and the transducer path. This problem was overcome by stretching a line across the river upstream of the gauged section, and tying a floating line to the midpoint of this. The line then floated downstream parallel to the direction of flow, enabling the angle to be determined by measuring the channel width at right angles to the floating line. It can also be seen that the channel widens towards the weir (the crest width is some 23 metres), which caused further problems with the setting up of the gauge parameters. It was finally decided to use the mean channel width in the gauged section (19.25 m) for all calculations of flow.

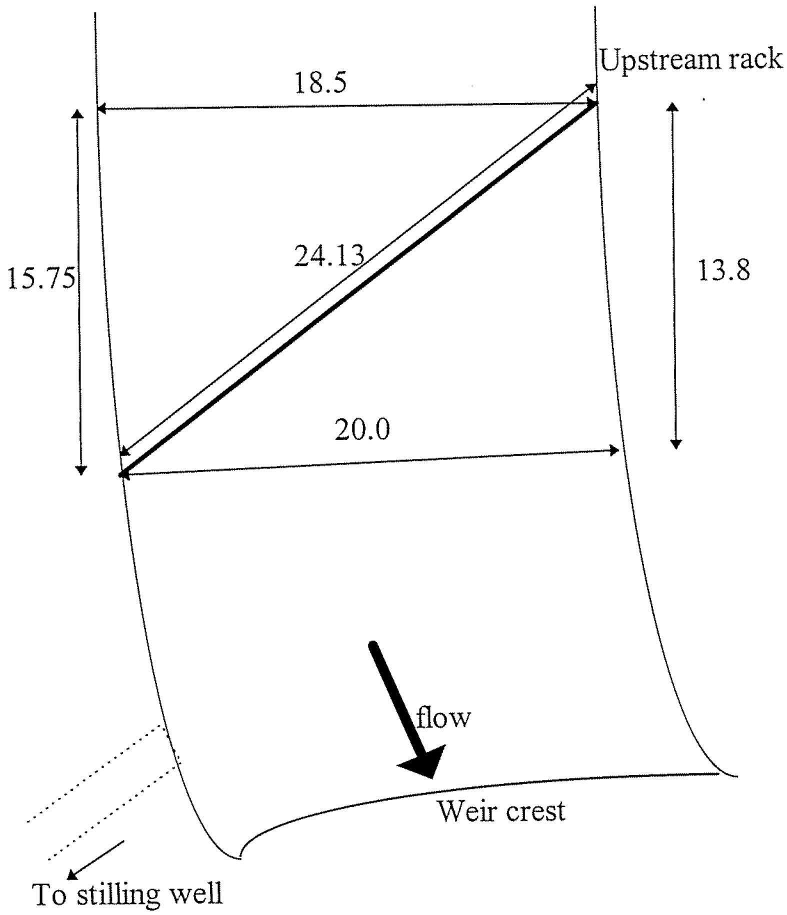


Figure 2.1 Schematic plan of the gauge installation at Blackford Bridge, showing the curved weir crest, gentle bend in the river and widening of the channel. All dimensions are in metres.

As the gauge had been loaned to the Project, and the gauging station is located in an urban area, the installation was undertaken in a slightly different manner to that at the other field sites. In particular, the cables were all routed underwater, both across and along the channel, which had an irregular bed. The cables were all tied to galvanised steel cables which were in turn tied to or threaded through hollow concrete blocks. Following reports from hydrometric staff working at the site a number of visits were made to clear weed from the cables during the summer months of 1997 - it is estimated that almost 1 tonne of weed was removed on one of the visits. Despite these efforts the steel cables were eventually broken during a relatively minor event (believed to be in August 1997). All remaining cables and transducers etc were then removed for salvaging.

The cables were reinstalled in the river in October. Instead of using steel cables once more it was decided to use galvanised short link anchor chain. 3/8" chain was used and was been most successful, despite major events having occurred. The chain lay flat on the river bed and, despite the far end being cut by vandals some time between April and August 1998, was still intact and weed free when the gauge was removed in December.

Whilst using the chain does present potential problems relating to manual handling legislation because of its weight, it was found that in practice it was much more straightforward to use than the steel wire and concrete block combination. By carrying the chain in a number of bins it was possible for two people to safely manhandle the chain from field vehicle to riverbank. Once on site, a catenary rope was then used to assist with pulling the chain across the river. A big advantage to using the chain is that it lies flush to the river bed and can be pulled back upstream following major events which have caused it to 'creep' downstream a little. It should also be longer lasting than the steel cable should it be used for a permanent installation.

3 SUMMARY OF EVENTS RECORDED AT THE SITE

A number of significant events were recorded at the site in both winter and summer months, and velocity data were collected from a total of five different levels. For the purposes of the majority of the analysis the event which recorded the highest level has been used for each velocity path. The only exception to this is the velocity data for the path deployed at -0.1 metres (stage datum), for which two events were used.

A summary of the principal events, and the data which were collected from these, is presented in Table 3.1. From this it can be seen that the criteria set out in Progress Report W6/i646/6 on 25th February 1997 were met, namely that two events had a peak level of greater than 1.2 metres, and all events had a peak level of greater than 0.6 metres.

Table 3.1 Summary details of the principal events from which velocity data were collected at the five different levels. All levels are relative to stage datum (metres).

Level of velocity path	Minimum stage	Maximum stage	Start date of event
-0.1 metres	0.077	0.416	10/06/97
	0.447	0.686	03/08/98
0.0 metres	0.271	1.228	07/01/98
0.2 metres	0.252	1.447	01/03/98
0.4 metres	0.445	0.688	04/04/98
0.6 metres	0.631	1.228	07/01/98

4 LEVEL MEASUREMENT

The first big event of the Project to occur at Blackford Bridge was in January 1998. The Agency quickly provided their archived data on disc, together with supporting information, and a preliminary analysis of the gauge data was then undertaken. This was forwarded to the Agency for discussion. A number of issues were raised as a result of this event, notably the accuracy of the stilling well levels due to the proximity of the well to the weir crest, and problems with the gauge measuring depth due to the transducer having been moved when the well was pumped. Despite moving the transducer this problem re-occurred during an event of similar magnitude in February. The depth transducer was subsequently re-sited, this time away from the steps in the well walls, which resolved the problem for the majority of subsequent events.

The gauge performed well in recording water levels in the stilling well, despite the occurrence of thermoclines during some events. To illustrate this, Figure 4.1 shows the levels recorded by both the 1408 gauge and the Agency shaft encoder during one event plotted against each other, together with the best fit linear regression line for the data. It can be seen from this that the data form a straight line, as one would expect, with the best-fit relationship close to unity. Given this and the fact that the 1408 gauge had failed to record accurate water levels during some of the events, as described above, it was decided that in order to ensure a degree of consistency all of the analysis would be based on the level data recorded by the Agency.

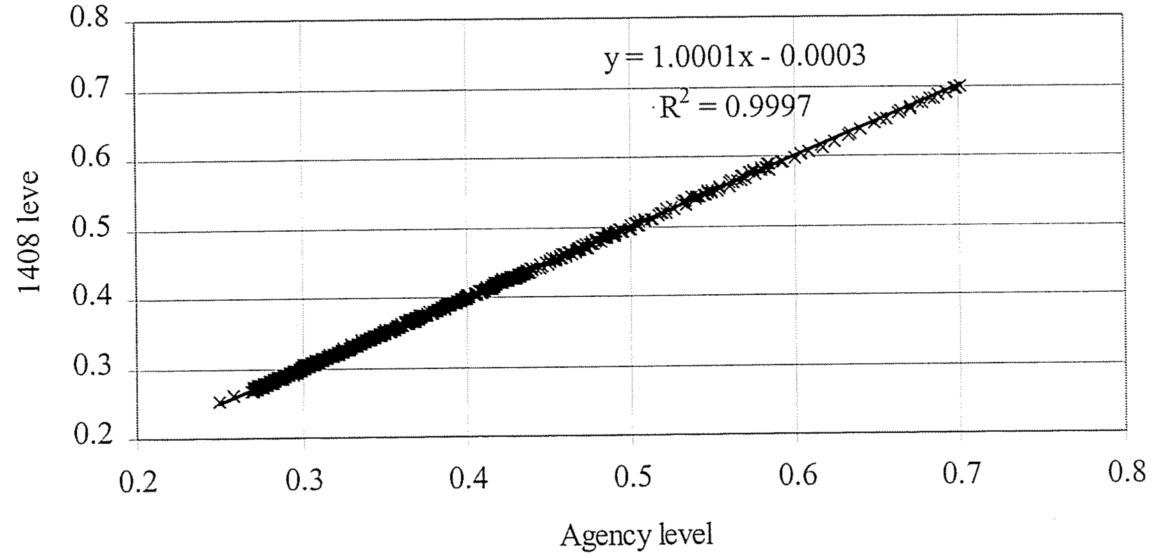


Figure 4.1 Water level data recorded in the Blackford Bridge stilling well by the Environment Agency shaft encoder plotted against the water levels recorded by the Peek 1408 ultrasonic gauge. All levels are expressed as metres, and are relative to stage datum.

5 VELOCITY MEASUREMENT

Path velocities were recorded for all events listed in Table 3.1, and are tabulated in Appendix ? to this site report. (*comment - or in Project Record if the site reports are to be contained as an Appendix to the Technical Report - Thoughts/preferences would be appreciated).*

As with the other sites used for the Project one of the first step of the analysis of the velocity data was to determine whether or not a single relationship between stage and velocity could be determined and, if so, quantify these relationships. However, the duplicity of data for some velocity path levels enabled an issue that had been previously identified and discussed by the Project Board in 1996 to be considered. This issue related to the extrapolation of data beyond the measured range; how far was it reasonable to extend data sets into the unknown? Whilst considering this point, it was also possible to evaluate some of the different types of trend-line that could be used to extend the data series.

In order to undertake this analysis the level and velocity data relating to the -0.1 metre (stage datum) velocity path were used, collected over two events starting on the 10th June 1997 and the 3rd August 1998. These data were plotted on the same axis, and different types of trend-line were fitted to the June 1997 dataset, which related to the lesser of the two events. The degree to which the trend-line fitted the August 1998 dataset was then evaluated, both visually and statistically. The combined series, together with the optimum trend-line, are presented in Figure 5.1.

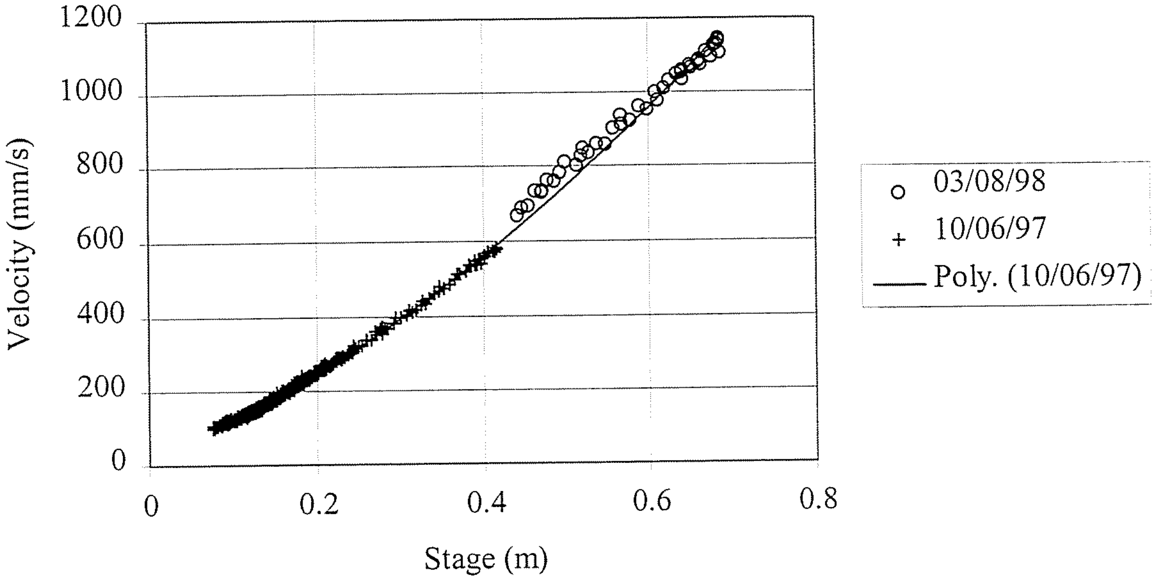


Figure 5.1 Stage and velocity data collected from the -0.1 metre (stage datum) for events occurring in August 1997 and June 1998. The best-fit trend-line for the June 1997 data series is also plotted.

From this analysis, and Figure 5.1, a number of points were noted:

1. The best fit trend-line, both visually and statistically, was a polynomial (in this instance a second order polynomial). This is the same form of relationship that had previously been used for deriving similar relationships at other project field sites.
2. In this instance, using a linear trend-line would significantly 'under predict' the velocities at higher water levels.
3. The trend-line derived from the June 1997 event was only based on data collected over a range of levels of only 0.34 metres, and up to a peak stage of 0.416 metres. Despite this, and the apparent discontinuity (*i.e.* jump or step) in the general trend visible in the two data series, the trend-line still bisects the data collected by the August 1998 event at a stage of almost 0.7 metres. This supports the earlier findings arising from the Greenholme data, namely that data collected during low flow events can be used to extend stage-velocity relationships to derive velocity data for higher river levels. However, due note must also be taken of any factors which may affect this, such as bank-full levels, non-modularity etc.
4. To counter the above point, it can also be seen that if the two data series were to be combined, it is probable that the best-fit trend-line would not follow the shape of that plotted in Figure 5.1. Instead, the line would be more of a flattened 'S' shape. Whilst the effects of this are minimal within the range of levels plotted in Figure 5.1, they would become more significant at higher levels where the 'single series' trend-line would produce a higher value of velocity for a given stage than that derived from a relationship based on the combined series.

The data series which contained the largest range in levels were thus used to establish stage-velocity relationships for each of the transducer path levels. The raw data, together with the best fit trend lines, are contained in Appendix A. The relationships for all series are plotted below in Figure 5.2.

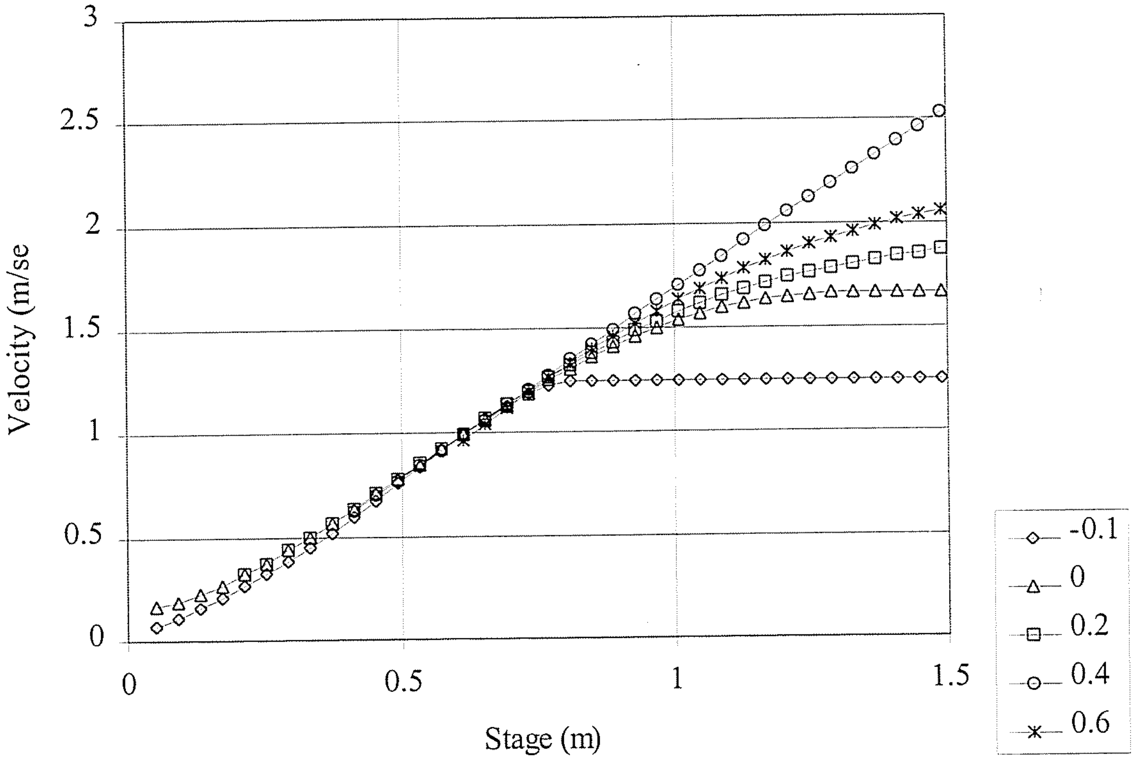


Figure 5.2 Stage/velocity relationships derived for the five velocity paths used at Blackford Bridge gauging station. Note that due to the nature of the polynomial used to extend the data series for the -0.1 and 0.0 metre paths, the velocities have been truncated off at a sensible limit. Had the relationships been used to extend the series beyond this point, the predicted velocities would have fallen. All levels are in metres, and are relative to stage datum.

It can be seen from Figure 5.2 that the five different relationships are virtually inseparable up to a stage of 0.75 metres. This may be due to the relatively deep at the site where the gauge was installed channel (mean bed level was -0.73 metres stage datum), and the fact that the gauge was installed a considerable distance upstream of the weir crest. Consequently, the velocity measurements will have been taken in the top half of the water column, well above any potential 'dead zone'.

Once the stage rises above 0.75 metres the stage-velocity relationships begin to separate. The 0.0, 0.2 and 0.6 paths follow a consistent pattern, reflecting the fact that their respective stage/velocity relationships are all based on events which a peak level of greater than 1.0 metres. Whilst it could be argued that the differences between the three curves at the highest stage are not as might be expected (i.e. the difference between the 0.0 and 0.2 paths is the same as that between the 0.2 and the 0.6 paths), this can be accounted for by the fact that the 0.0 data were levelled off at a stage of 1.3 metres, causing the peak values to be lower than those likely to be encountered in reality.

However, the -0.1 and 0.4 metre paths appear to be less consistent. In particular, the 0.4 metre path, being based on a near-linear relationship, appears to significantly overestimate the velocity for a given stage. In contrast to this, due to the nature of the polynomial applied to the -0.1 metre data series, the velocities at this path height appear to be less than would be expected due to the 'predictive' nature of the relationship having to be curtailed just above a stage of 0.8 metres to prevent the velocities falling.

Placing these observations into some kind of perspective, it would appear that the extent to which a stage/velocity relationship based on a data series of limited range can be extended is itself limited. Whilst it is possible to derive a series of linear relationships for each of the data series which <u>would</u> form a family of parallel curves if plotted as Figure 5.2 above, the data collected during the high flow events do not support a simple linear extrapolation. This is best illustrated by the 0.0 and 0.2 data series plotted in Appendix A, which both show the velocities levelling off at high river levels (i.e. above a stage of 1 metre).

If it is remembered that the total channel depth during an event with a stage level of 1.5 metres is in excess of 2.25 metres, it is reasonable to assume that there is unlikely to be any significant difference between velocities recorded at -0.1 and 0.0 metres. Similarly, it would appear to be sensible to favour the more realistic 0.2 and 0.6 metre relationships to that derived from the 0.4 metre path.

6 DETERMINATION OF FLOW - THE STAGE VELOCITY APPROACH

The analysis relating to the ability of the gauge to measure flow had to be undertaken in a different order for Blackford Bridge than at other Project sites. This is due to the acknowledged uncertainty in the Agency rating for the site; in order to assess the performance of the gauge it was first necessary to establish a standard against which comparisons could then be made. It was thus decided to derive a stage-discharge rating for the site based on the stage-velocity relationships described in Section 5.

The method adopted for this was the same that was developed from the Greenholme data collected earlier in the project. It is based on using the stage-velocity relationships to determine stage-discharge values for each horizontal 'slice' of the river, with each slice being represented by one of the transducer paths. The flow from each of the 'slices' is then totalled to give the total river flow for a given stage.

The following individual steps were undertaken:

- The stage velocity relationships were established, as set out in Section 5.
- The most suitable relationships were then selected for use to determine the rating. In the case of Blackford Bridge, the 0.0, 0.2 and 0.6 metre paths were used.
- The stage-velocity relationships were used to determine velocities for differing stages, rising from 0.3 to 1.5 metres above stage datum, rising in increments of 0.01 metres.
- The lowest velocity path (0.0) was used to calculate the discharge in two slices. The lower slice ranged from the mean bed level (-0.73 metres) to the midpoint between the bed and the path height (i.e. it was 0.365 metres high). This height was then multiplied by the path velocity for each stage and the path length (19.25 metres), and the result was then multiplied by the 'bed correction factor' to give the slice discharge ($Q_{1,1}$). This parameter is designed to take account of the reduced velocities adjacent to the river bed, and is set by the gauge operator. Whilst it has been demonstrated that improvements do arise from optimising this value at some of the study sites, for the purposes of this site the value was set to 0.67. This value was obtained when the gauge was first commissioned by adjusting it until the gauge 1-minute flow corresponded with the flow derived from the Agency rating (under low flow conditions). It is suggested that at ungauged sites the 'Agency rating flow' could be replaced by a good quality current meter gauging.
- The upper of the two slices to which the lowest velocity path data were applied ranged from 0.365m below stage datum to the midpoint between the 0.0 and the 0.2 metre velocity paths, i.e. 0.1 metres. Whilst in practice this could mean that the velocity path could be used to determine the lowest flows (i.e. with a stage < 0.1 m) on its own by setting the 'slice' upper limit to the water surface, this was not necessary as the Project was concentrating on mid and high flows. The slice height was then multiplied by the path velocity and path length to determine the slice discharge ($Q_{1,2}$).
- The next velocity path was then used to determine the discharge of the next slice, $Q_{2,}$ in the same way. The height of this section ranged from 0.1 metres to the water surface, until levels reached 0.6 metres at which time the next velocity path would be covered. When this occurred the upper limit of the 0.2 metre slice was set at the midpoint between 0.2 and 0.6 metres, i.e. 0.4 metres.
- Finally, the highest velocity path was used to determine the discharge of the top section of the river, Q_3. The height of the slice ranged from 0.4 metres to the water surface.
- Once each of the component discharges $Q_{1,1}$, $Q_{1,2}$, Q_2 and Q_3 had been calculated, they were summed to give the total discharge for the river for each stage.

The stage discharge rating arising from this analysis is plotted in Figure 6.1, together with the Agency rating for the site and a theoretical rating developed by Hydraulics Research.

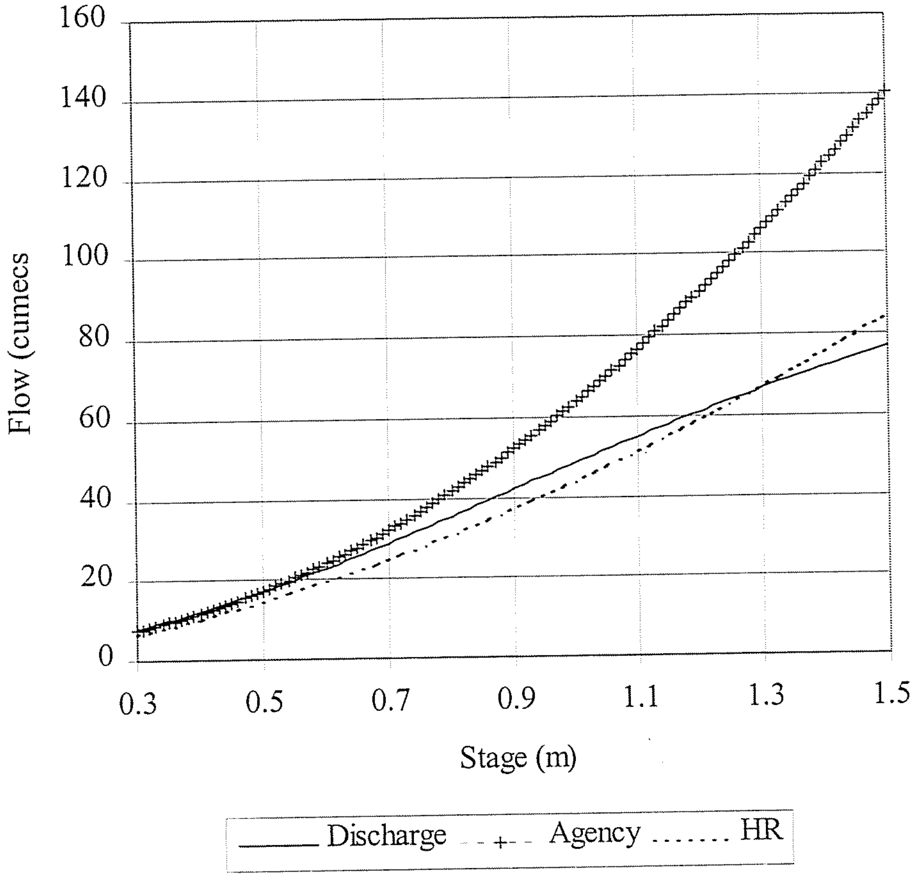


Figure 6.1 The rating curve derived by the stage-velocity method (Discharge) plotted against the Environment Agency and HR ratings for Blackford Bridge.

It can be seen from Figure 6.1 that the rating derived from the ultrasonic gauge data closely follows the Agency rating derived by current metering up to a stage of approximately 0.6 metres. At this point the gauge rating diverges from the Agency curve, producing a lower flow for a given stage. From this point of divergence it follows the same general pattern as the curve derived by HR, but producing consistently higher flows (typically 2-3 cumbers). However, above a stage of 1.1 metres the gauge rating begins to flatten, crossing the HR rating at a stage of 1.3 metres. From this point on the gauge rating produces the lowest flow for a given stage of all three ratings.

It would appear that, within the measured range of flows (i.e. up to a stage of 1.2 metres) the rating derived from the gauge data produces a compromise between the HR and Agency curves. Reassuringly, the gauge rating follows the Agency curve for the majority of the range calibrated by current metering (more than 95% of the Agency gaugings have been carried out for a stage of 0.6 metres or less). Appendix B contains details of the gaugings carried out above a stage of 0.6 metres (a total of 12), together with the entire gauging record plotted on the rating curve. It can be seen from this that the data confirm the lower half of the plot shown in Figure 6.1, i.e. flows as high as 56 cumbers have been gauged at a stage of 0.94 metres.

The reason for the differing values of the ultrasonic gauge rating and Agency gaugings has a number of possible explanations, including:

1. The ultrasonic gauge is incorrect;
2. The gaugings are incorrect;
3. There is a consistent bias in one or other of the measurements involved with either method.

It is considered to be unlikely that either of the first two explanations is likely to be the cause of the problem. The ultrasonic technology is well proven, and the methodology being used in this case has worked at other Agency sites. Similarly, the gaugings were undertaken over a period of more than twenty years, by a number of operators and with a variety of current meters. This would suggest that there is a consistent bias in one or more of the measurements or analytical steps that have been followed.

It has already been noted that the rating curve derived from the ultrasonic gauge flattens out over the higher part of the range. As there is no valid hydraulic explanation for this, it is most likely due to the use of polynomials in the stage/velocity relationships, as described earlier in Section 5. It was thus decided to focus on the rating curves in the range 0.6 to 1.2 metres, i.e. between the point of divergence and the maximum level for which velocity were collected. They are thus re-plotted over this range in Figure 6.2.

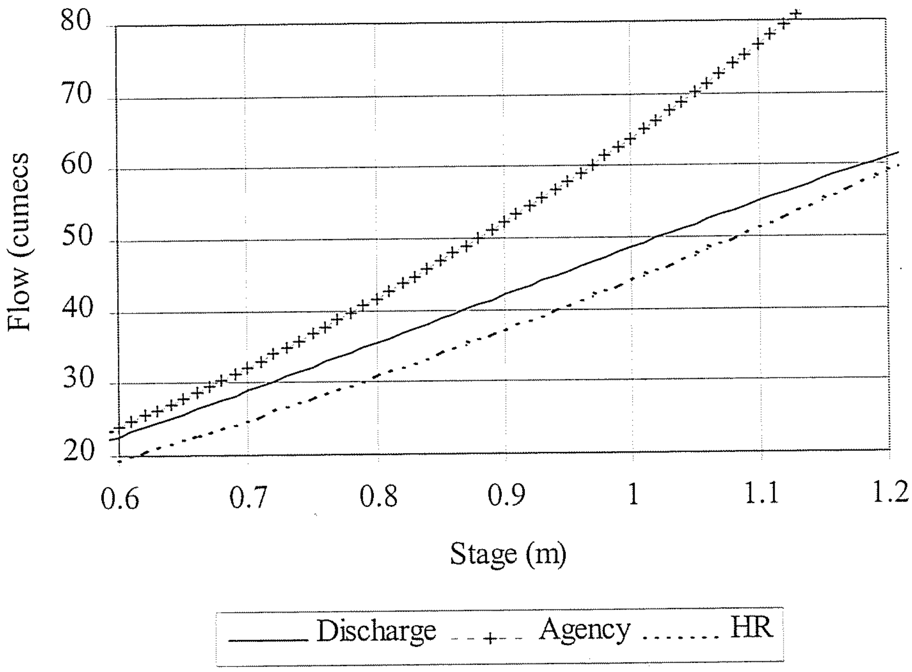


Figure 6.2 The rating curve derived by the stage-velocity method (Discharge) plotted against the Environment Agency and HR ratings for Blackford Bridge between stages of 0.6 and 1.2 metres.

When the range in levels is reduced to that presented in Figure 6.2 it can be seen that the ultrasonic gauge rating effectively crosses from the Agency to the HR curve. A report produced by the NRA in 1992 (also contained in Appendix B) addressed the issue of the Blackford Bridge rating, and concluded that flows around a stage of 1.0 metres the rating was considered to be consistent with the measured flows. It also concluded that the theoretical rating based on a basic broad-crested weir was unlikely to be sound as the Blackford weir was a non-standard crescent shaped old mill weir with a broad crest, suggesting that this curve is less likely to be the 'correct' one. This means that we have to consider possible causes for the discrepancy of 15 cumecs (almost 24%) in flows between the Agency and ultrasonic gauge ratings at the 1 metre level. There are two possible explanations that may assist with this, described below.

Difference between measured and true water level

Whilst on site during one of the more significant events it was noted that the staff gauge level, to which the downstream set of transducers was mounted, was significantly higher than the level in the stilling well, the entrance to which was located some 20 metres downstream, immediately upstream of the weir crest. The difference at that time was of the order of 50 mm. Enquiries were made with the Agency to see if this phenomena had been previously noted, to which the reply was affirmative (the correspondence relating to this is also contained in Appendix B). Table 6.1 contains the recorded differences between well and staff gauge readings, plotted in Figure 6.3 together with the best fit linear regression line.

Table 6.1 Mean differences between stilling well and staff gauge readings for different recorded levels in the Blackford Bridge stilling well.

Well level (m)	0.486	0.52	0.348	0.42	0.636	0.411	0.399	0.826
Difference in levels (mm)	5	16	4	3	24.5	5	4.5	29.5

From Figure 6.3 it can be seen that draw-down over the weir has a progressive effect in lowering stilling well levels below those at the staff gauge, located further upstream. Extending the best fit line would suggest that the difference at a stage of 1.0 metres is approximately 45 mm. Thus, at higher flows, the true water depth above the ultrasonic gauge would have been higher than that recorded in the stilling well. An additional 45-50 mm would add between 1.5 and 2 cumecs to the gauge flow, helping the situation a little but certainly not resolving the problem.

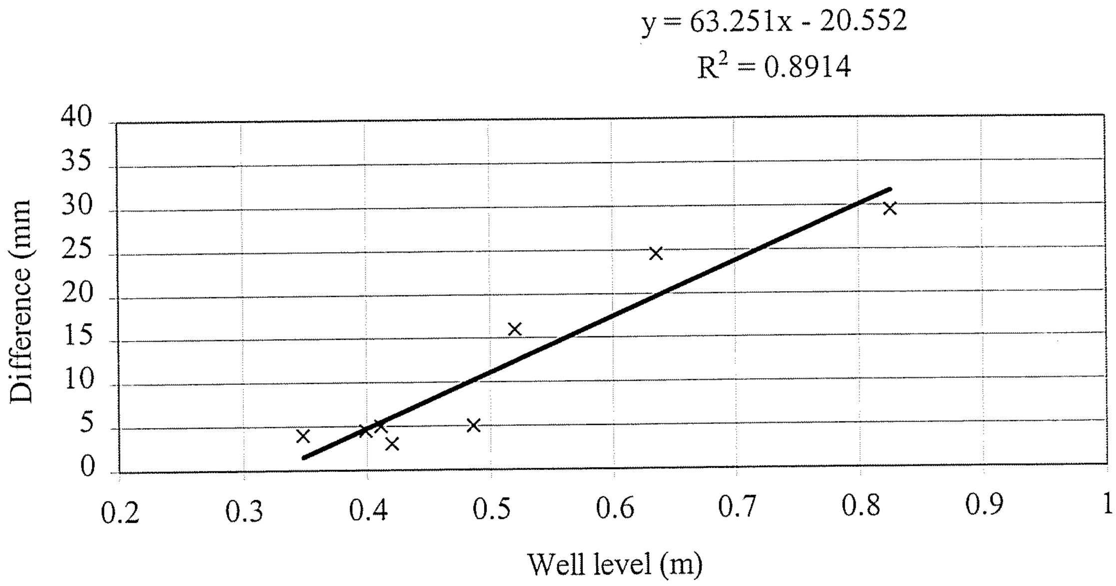


Figure 6.3 Differences between stilling well level and staff gauge levels at Blackford Bridge plotted against stilling well level, together with the best fit linear regression line for the data series.

Consistent overestimation in high flow current meter gaugings

The Agency measure high flows at Blackford Bridge by gauging from a road bridge, well upstream of the station. The bridge is both high and wide, and spans the same gentle curve in the river as the ultrasonic gauge, but further upstream. Possible systematic errors in the high flow gaugings (only five of which have been above 0.8 metres) include:

- Skewed flow due to the orientation of the bridge over the channel
- Errors in depth measurement in the gaugings due to having to use a relatively light sinker weight in very fast moving water. It is not known what size of sinker is used by the Agency when bridge gauging, but to ensure near-vertical suspension cables the sinker weight would need to be of the order of 25 kg at the mean 0.6 metre path velocity recorded by the ultrasonic gauge. As it is inevitable that surface velocities towards the outside of the bend of the river would be higher than the mean velocity of a sub-surface path a higher sinker is likely to be required. If too light a sinker weight was used, and it resulted in the cable being oriented at an angle of 30^0 to the vertical, the water depth measurements would be systematically increased by over 15%.

Whilst these explanations are all reasonable, they do not allow a decision to be made as to whether the Agency or gauge rating is likely to be the 'correct' one. The reality is that it probably lies somewhere between the two, with a flow of between 50 and 55 cumecs occurring at a stage of 1.0 metres. For the purposes of the Project it is questionable whether or not this really matters; other sites have been used for which there is greater confidence in the Agency rating. What has been demonstrated is that from a relatively short period of gauge deployment, and very few events, it has been possible to derive a rating for a known 'problem' site that lies midway in the current range of potential ratings.

7 GAUGE PERFORMANCE

For other field sites used in the Project the gauge performance has been assessed by looking at individual events. This has enabled the actual physical performance of the gauge (i.e. whether or not it works) to be evaluated, together with comparing the flows recorded by the gauge to those produced by the Agency rating. Given the uncertainty described in Section 6 above it was decided to assess the gauge performance over the two main events which occurred during the course of the monitoring of the site, and compare the gauge flows to those produced by the ultrasonic gauge rating. In this way the analysis would assess the difference in flows arising from the use of a limited number of events. The two events that were used for the analysis are summarised below in Table 7.1, and are plotted in Figures 7.1 and 7.2.

Table 7.1 Details of the two events used for the assessment of gauge performance at Blackford Bridge.

	Start date/time	Finish date/time	Minimum stage (m)	Maximum stage (m)	Velocity path heights (m)
Event 1	8 January 1998 at 0815	10 January 1998 at 1400	0.389	1.212	0.0 and 0.6
Event 2	2 March 1998 at 2000	10 March 1998 at 0730	0.249	1.460	0.2

It can be seen from Figure 7.1 that, when working, the gauge flow is virtually inseparable from the rated flow derived by the stage-velocity method. This is hardly surprising as this event formed the basis for two thirds of the relationships used to derive the rating. However, it does show that there does not appear to be any significant difference in flows arising from there being a reduced number of velocity paths which are inevitable further apart.

However, and as with some of the previous sites, it can be seen that the gauge failed at the top end of the recorded flows. The boundary between the gauge working and failing was lower on the rising limb than when flows were receding (1.0 and 1.1 metres respectively), again as found at other sites. Another observation common to previous events is that it was the higher of the two velocity paths which failed first, and which was the last to 'reconnect'. This would appear to support the view expressed in some of the Progress Reports that the working limit of the velocity paths is likely to be a function of path length, sediment concentration and channel velocity.

Figure 7.1 Gauge flow plotted against the rated flow for event number 1 at Blackford Bridge between January 8th and 10th 1998, velocity paths at 0.0 and 0.6 m

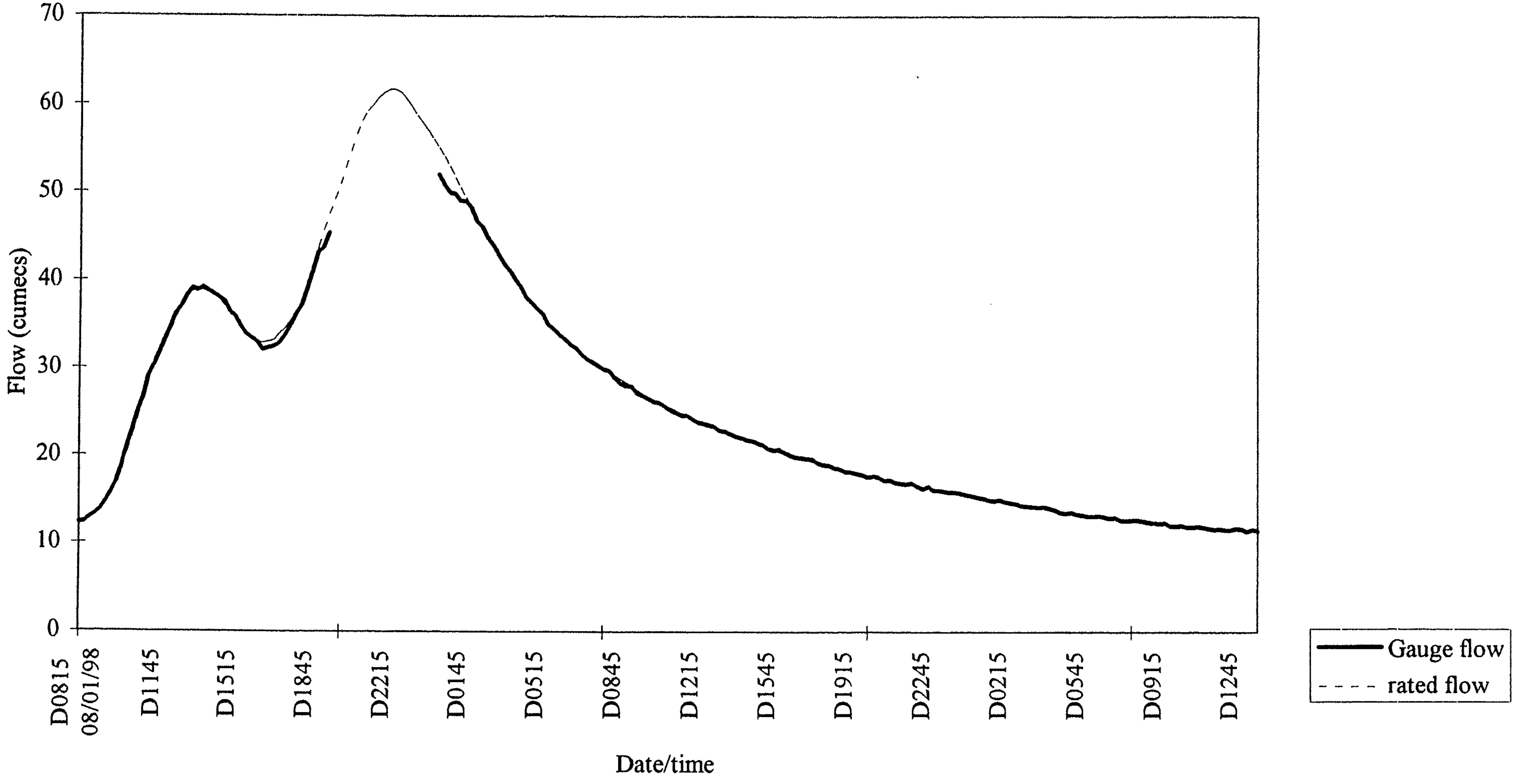


Figure 7.2 Gauge flow plotted against the rated flow for event number 2 at Blackford Bridge between March 2nd and 10th 1998, velocity path at 0.2 metres

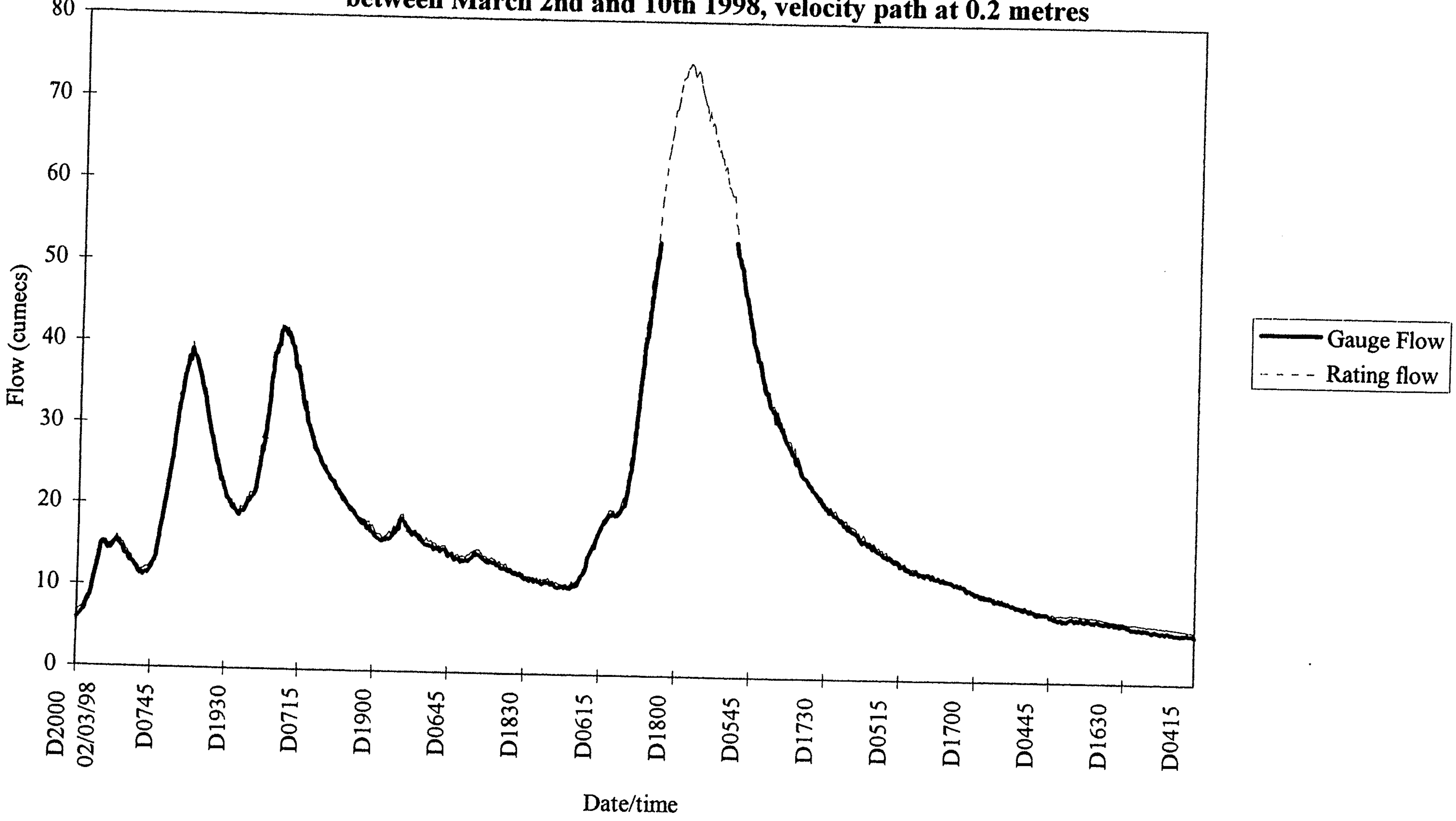


Figure 7.2 further confirms the observations based on Figure 7.1. If anything, the gauge flow is even closer to that derived by the rating for medium-high flows (i.e. 20-50 cumecs), although it does tend to produce lower values at lower flows. If it is considered that the gauge only had one velocity path working during this event (the upper path had been vandalised) then the results are even more encouraging.

It can also be observed that the velocity path failed and 'reconnected' at approximately the same level on this event, equating to a stage of between 1.1 and 1.15 metres. The fact that the gauge was able to work for longer during rising flow conditions may be explained by the two lesser (but still significant) high flow events which occurred during the previous three days. It is likely that these will have flushed much of the surface sediment through the system before the main event occurred.

It is perhaps useful to place the stage at which the gauge failed on these two events into some kind of context. Table 7.2 below is a summary of peak over threshold data for the site.

Table 7.2 Summary peak over threshold analysis for Blackford Bridge river levels recorded between 1976 and 1999. (Thanks to Alison Hanson for the data used to produce this table).

Stage threshold 0	1.5 metres	1.2 metres	1.0 metres
Number of peaks over threshold between 1976 and 1999	5	30	74

It can be seen from Tables 7.1 and 7.2 that both events one and two were certainly of a significant nature; event one peaked at a level similar to that which would be expected to occur once a year, whilst event two was even rarer still (it was actually the sixth highest event recorded at the site). Perhaps ironically, within a few weeks or removing the gauge from the site, this event was topped by the fifth highest event recorded at the site!

The level at which the gauge failed, i.e. between 1.0 and 1.1 metres, equates to an event that would, on average, be expected to occur twice a year. It can thus be concluded that the gauge actually performed remarkably well, and was able to cope with major events from a heavily urbanised catchment which is likely to have high sediment loads.

8 CONCLUSIONS

It would appear that the decision to deploy a third gauge at Blackford Bridge was well rewarded, with a number of useful findings arising from the studies at the site. While the work has possibly resulted in as many questions being raised as answered, it has certainly made a useful addition to the debate regarding the most suitable rating for the station. With regard to this Project, the following points summarise the main findings of the analysis presented in this site report:

1. It was possible for two personnel to successfully install and commission the gauge in less than one day, including the underwater cable/concrete block installation and aligning the transducers without the use of an oscilloscope.
2. Whilst the cable/block combination was able to function throughout the first eight months of 1997, it eventually failed due to becoming 'ragged' with weed. When it failed, the force was so strong that the galvanised wire rope actually snapped.
3. The replacement configuration of 3/8" short link chain worked throughout a whole 12-month period, despite being disconnected by vandals. It was not subject to as much fouling by weed, and was not affected by the two biggest events recorded at the site during the monitoring period. The chain could be safely handled by two personnel and, after a little thought, was relatively easy to install across the river.
4. When installing the gauge, it was found that the most accurate method of identifying the angle of the transducer paths to the direction of flow was to use a floating line down the centre of the channel section, and to take measurements from this.
5. The ultrasonic gauge worked well in a relatively dirty, large urban river. The path length of over 24 metres was the second longest used during the Project.
6. The transducer rack system also functioned well; transducers could be raised, lowered or removed in a matter of minutes by one person, and did not require re-alignment when deployed at different levels.
7. When working the depth transducer measurements were virtually identical to those recorded by the Agency shaft encoder. The only time the depth transducer failed was after the well had been pumped, following which the transducer was inadvertently moved to be below one of the metal steps in the well.
8. The velocity data collected at the site provided clear and consistent relationships with river level.
9. Whilst it was possible to extend these relationships beyond the measured range, or use then to fill in gaps in the data, it was found that due care was needed to ensure that the statistical relationships gave sensible values. In particular, data series collected during relatively minor events were found to be unsuitable for establishing stage-velocity relationships at higher levels.
10. By selecting the most suitable stage-velocity data series it was possible to construct a stage discharge relationship for the station. This was extended to a stage of 1.5 metres, equivalent to the five highest events recorded at the site in 23 years.
11. Whilst there is considerable uncertainty regarding the Agency rating at the station, the rating equation produced by the stage-velocity approach was able to closely follow this up to a stage of 0.6 metres. At this level the curves began to separate, with the gauge rating lying between that used by the Agency and one produced by Hydraulics Research for the site. It was possible to identify a number of possible reasons for the differences between the Agency and gauge ratings.
12. When operating as a 'stand-alone' gauge the equipment was able to function well to levels in excess of 1.0 metres, equating to the highest two events of the year. There appeared to

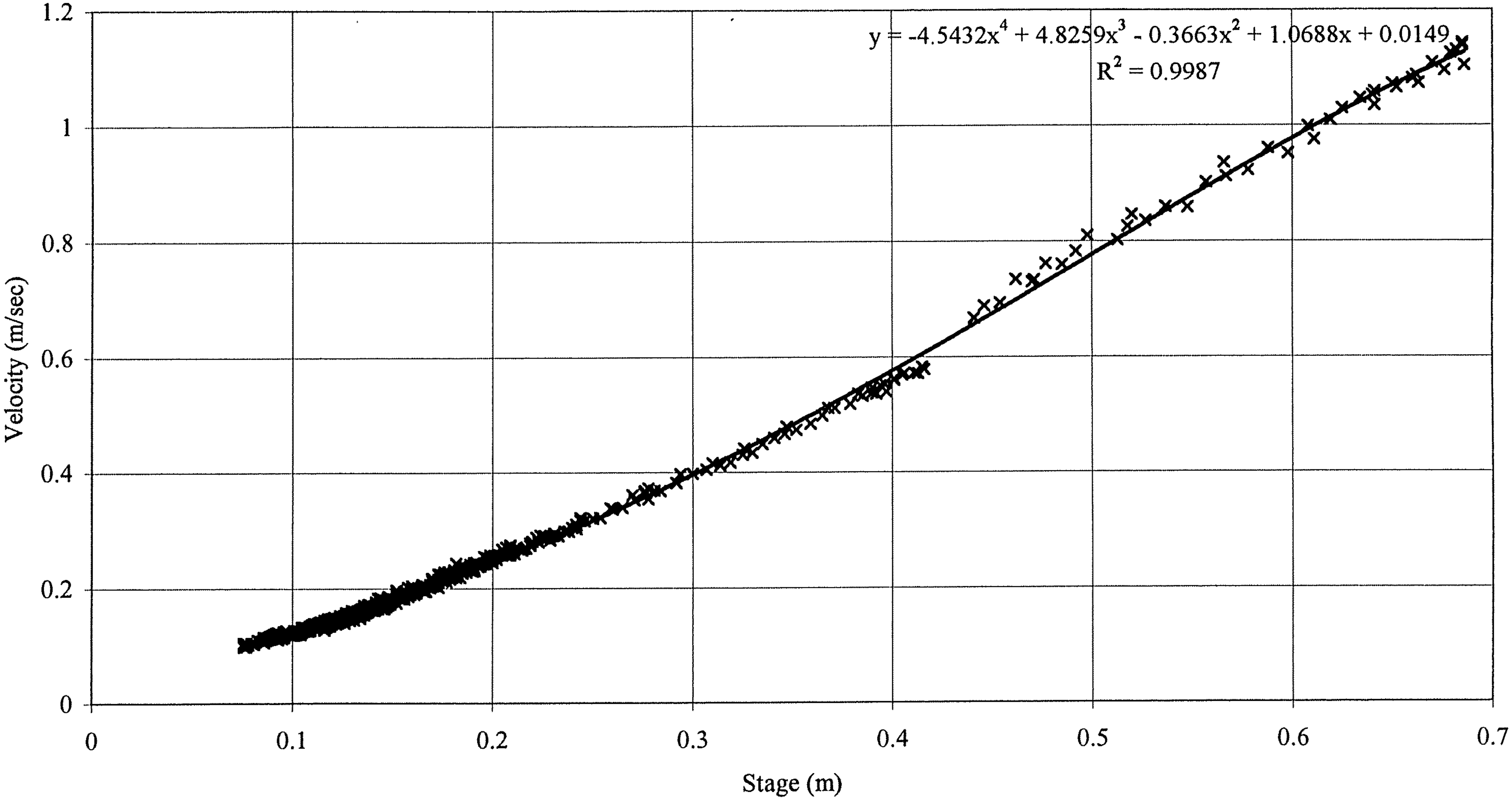
be no significant difference arising from one, two or three velocity paths being used to calculate the flow.

13. As with other sites there was a level at which the gauge ceased to function. It is considered that this was due to sediment load, a function of path length, sediment concentration and path velocity. Again, as with other sites it was noted that the gauge was able to work at higher levels during receding flows during one of the two events.
14. During the period that the velocity paths failed, the data collected by the gauge could be used to derive flows using the stage-velocity approach. Whilst the uncertainty associated with this is obviously greater than that involved with measured data, it is considered that this method still produces acceptable estimates of the flow.

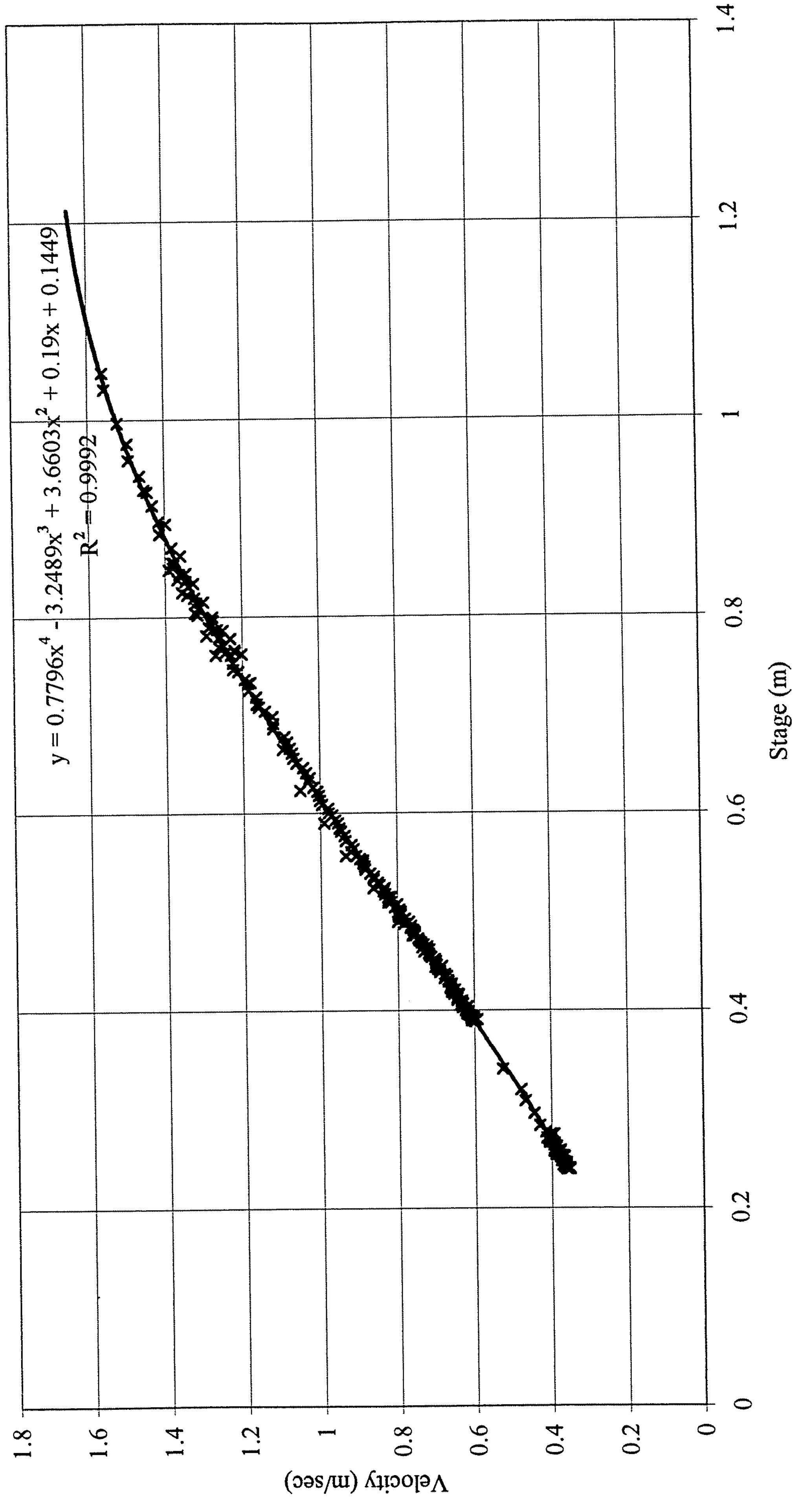
APPENDIX A

Stage velocity relationships for the transducer path data collected at Blackford Bridge gauging station between April 1997 and August 1998

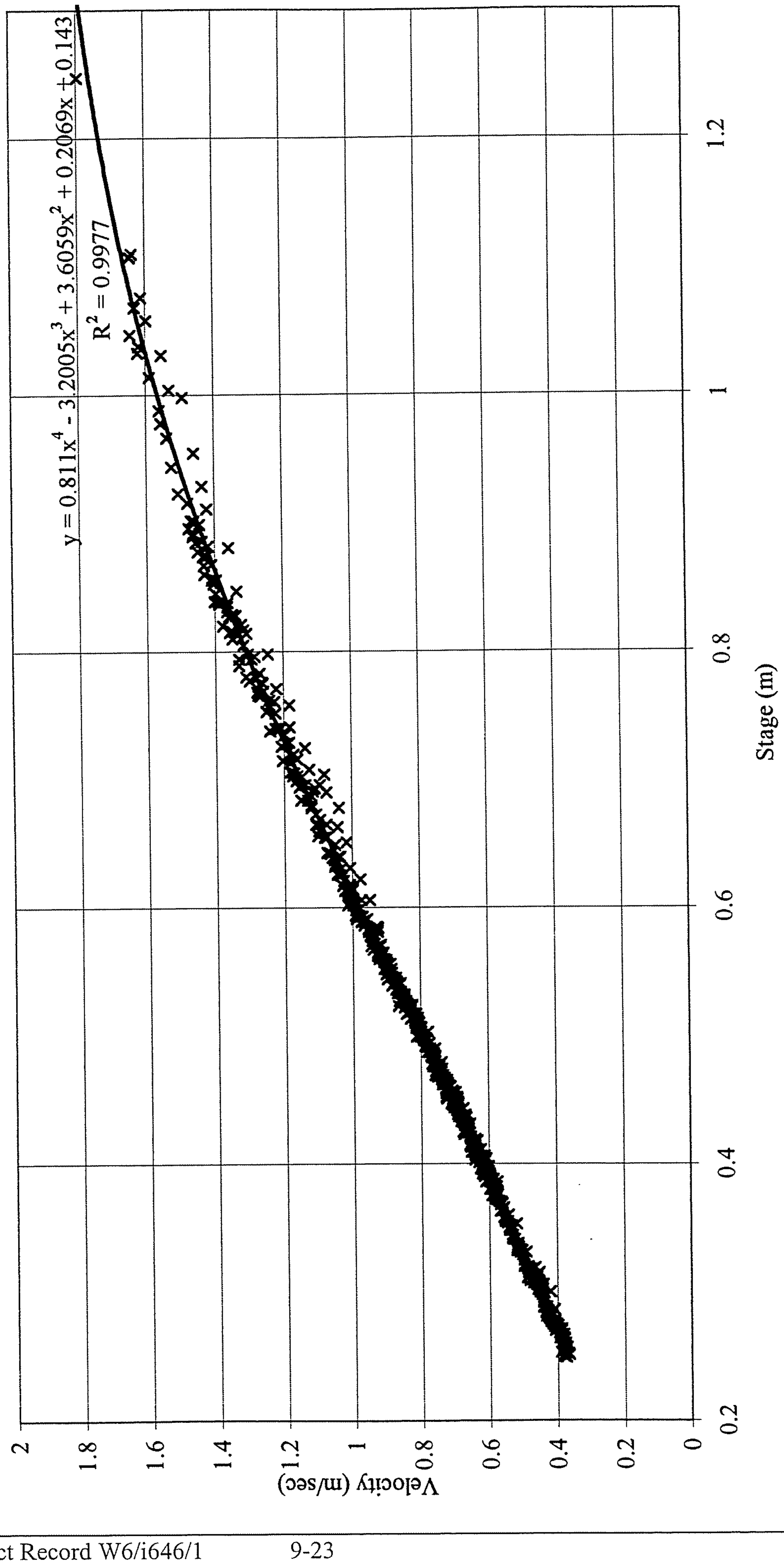
Stage/velocity data and the best fit line for the -0.1 metre velocity path



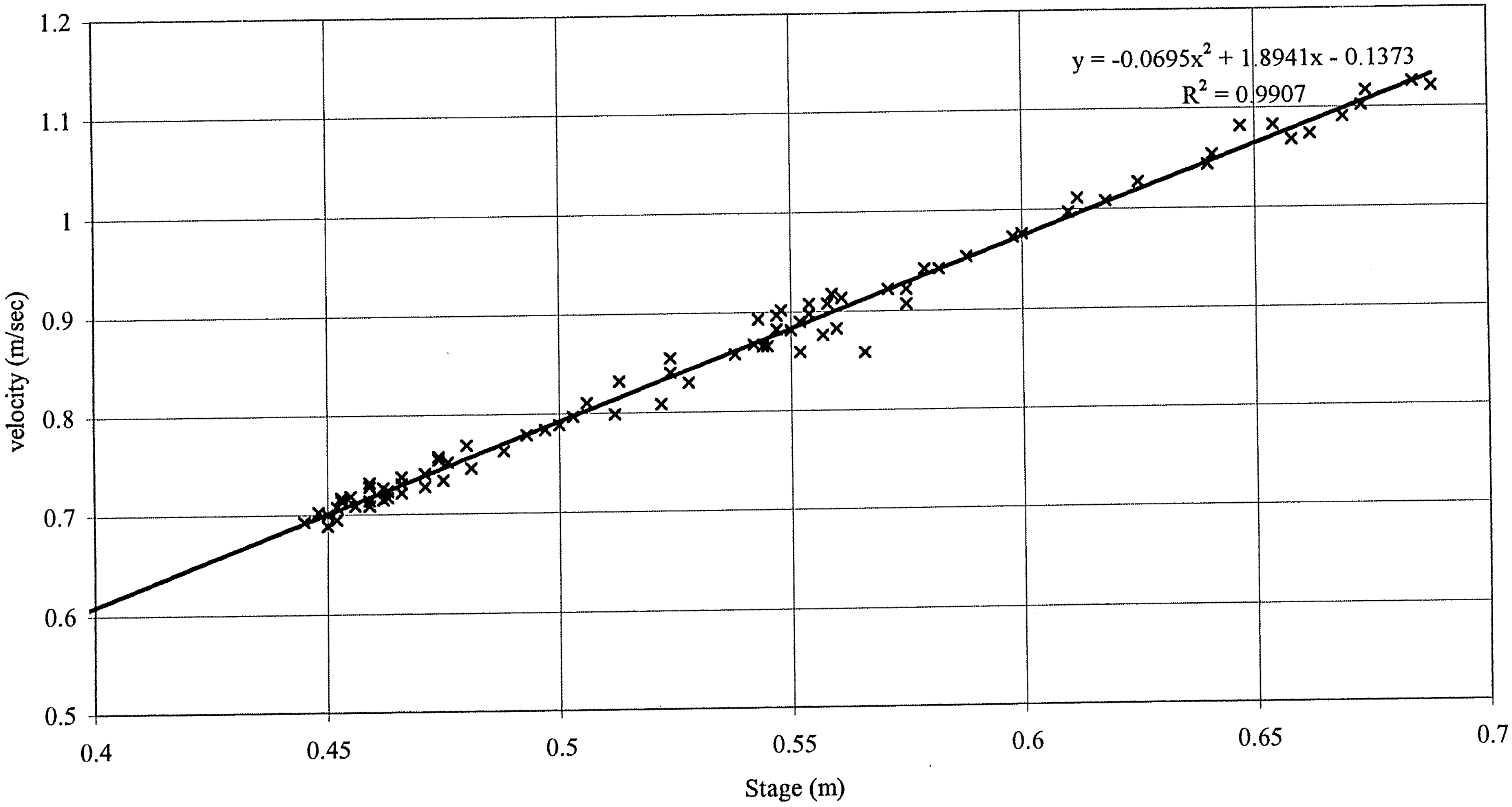
Stage/velocity and the best fit line for the 0.0 metre velocity path



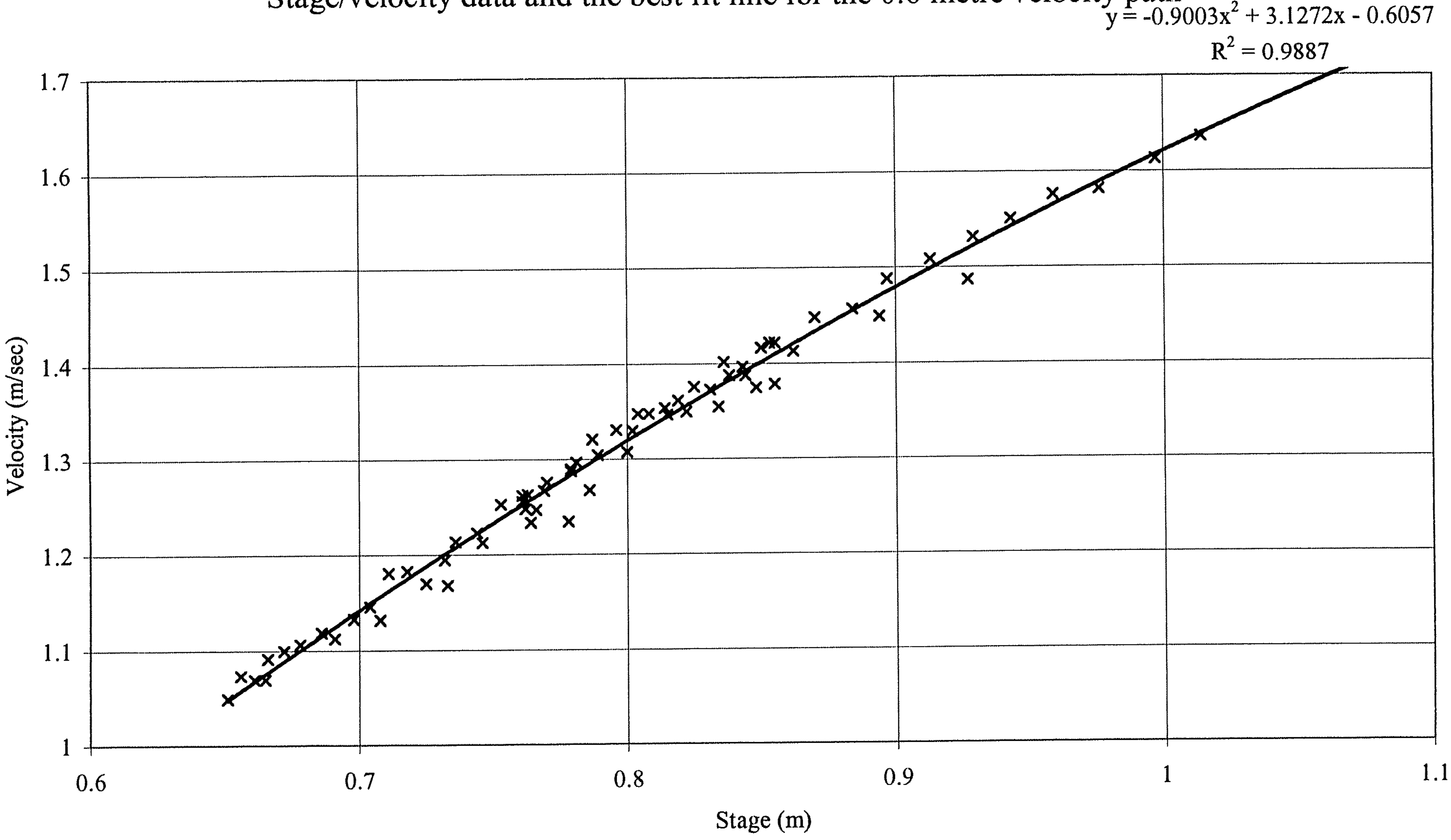
Stage/velocity data and the best fit line for the 0.2 metre velocity path



Stage/velocity data and the best fit line for the 0.4 metre velocity path



Stage/velocity data and the best fit line for the 0.6 metre velocity path



APPENDIX B

Copies of Environment Agency/NRA data and reports relating to the stage discharge relationship for Blackford Bridge gauging station. The information relates to three separate topics:

1. **A 1992 report relating to the extrapolation of the stage-discharge relationship;**
2. **A copy of the Agency rating curve with current meter gaugings plotted, together with details of the high flow gaugings carried out at the site;**
3. **Data relating to the difference between staff and well levels during high flow events.**

RIVER ROCH AT BLACKFORD BRIDGE (690205)

STAGE-DISCHARGE EXTRAPOLATION

Introduction

Two stage-discharge relationships existed for Blackford Bridge. The original equation had been theoretically calibrated by the Mersey River Board and used for flood studies:

$$Q = 3.09 \times 80 \times H^{1.5}$$

where Q was in cusecs and H was in feet. This equation covered data before 1976. The second equation dated from 1/1/76 and is still currently in use:

$$Q = 44.558\ (H + 0.173)^{2.408}$$

However, the two equations were not consistent and calculated almost double the flows for the same level at higher flows (e.g. 118 m^3s^{-1} and 288 m^3s^{-1} respectively at 2.0m). Investigation was required.

All heights referred to in this document are in metres above the instrument datum unless stated otherwise.

Report

A cross section of the station was obtained from the Area office. This was planimetered for area and measured for wetted perimeter. Two methods of stage-discharge relationship extrapolation were investigated for comparison.

The cross section had been drawn up to the top of the retaining wall on the left bank (2.69m). Although the height of bank full is 4.922m the maximum level ever recorded at the station was 2.085m in October 1980. The maximum height at which a gauging had been carried out was 0.942m on 11th March, 1979. The cross section shows the right bank to be natural whereas the left bank has a retaining wall from 1.09m up to 2.69m. Therefore, there is a significant break in slope above 1.09m although there have been no gaugings carried out above this height to reflect it.

From the cross section it was possible to estimate flows up to 2.69m using the velocity-area and the hydraulic mean radius methods of extrapolation. Estimated flows at this height were comparable, 464 cumecs for the velocity area method and 453 cumecs for the hydraulic mean radius method.

The two existing equations, theoretical pre 1976 and calculated post 1976, were plotted on the same graph along with all gaugings. The gaugings corresponded to the calculated relationship showing flows are much higher than established with the pre 1976 relationship. This was a basic broad-crested theoretical equation with no notes or documentation. However, the weir at Blackford Bridge is not a standard broad crest but a non-standard crescent shaped old mill weir with a broad crest.

Conclusions

There is no reason why the post 1976 equation should not continue to be used, the gaugings fitted and the flows around 1.0m were consistent when compared with the estimated flows of the velocity area and the hydraulic mean radius methods.

The equations for Blackford Bridge are:

$$Q = 44.558\ (H + 0.173)^{2.408}$$

possibly valid from the beginning of the station records, pending further investigation, but certainly valid pre 1976 up to a height of 0.823m

and

$$Q = 53.44\ (H + 0.089)^{2.085}$$

S.E. of Estimate	1.88
S.E. of Mean Relation	0.3623
Correlation Factor	0.99993

valid throughout the station history from 0.823m up to 2.69m.

Comment

Due to the change in slope at approximately 1.09m flows between 0.8m to 1.2m may be over estimated slightly (up to a maximum of 6 cumecs, which is around 10%).

Although there is no obvious change in slope around 0.8m, the change point of 0.823m between the lower and upper equations was chosen because this was the level that the lower equation crossed the upper on extrapolation.

Vicky Schofield
16th March, 1992

Our ref
Your ref

Date 21/01/98

ENVIRONMENT AGENCY

Tony Bennett
Scotia Water Services
Belton House
Wanlockhead
Biggar
ML12 6UR

Dear Tony

DATA FOR RIVER ROCH AT BLACKFORD BRIDGE

Sorry for the delay in forwarding the data to you, I'm afraid we're rather snowed under at the moment. Hopefully in future it'll be faster !

Enclosed is the data you requested, two diskettes with flow data on one and level on the other. I am aware that the 1997 files are rather long (30,000 plus lines). If you are using a spreadsheet then this may create problems for you - let me know if you require split files. Some spreadsheets will not like the SCF suffix so that will also need to be changed to TXT.

The existing rating for the station is:

$Q = 44.558 * (H + 0.173) ^\wedge 2.408$ to 0.823
$Q = 53.44 * (H + 0.089) ^\wedge 2.085$ to 2.69

A diagram of this is enclosed - with all gaugings plotted, as you can see it's somewhat "approximate". The single rating has been used for entire period of record and so it is not of a terribly high quality. We're hoping in future to be able to improve it. As for copies of the ratings produced by consultants as part of other projects - I don't have copies of them, I tend to get flashing glimpses of the documents but i'll have a word with Peter Spencer.

I've also enclosed the copies of gaugings above 0.6 for entire period of record as requested.

Your assumption on the level measurement used when gauging is correct. One of the reasons is that there is a delay in the river level transferring to the well and under some circumstances there is a significant difference in the level. What is the correct method ? Either you run the risk of misreading the staff gauge or adding errors if the staff gauge has shifted, or alternatively you use the well level which doesn't reflect the river conditions ! Anyway, its all good fun.

The Environment Agency
P.O Box 12, Richard Fairclough House Knutsford Road Warrington. WA4 1HG
Tel: 01925 653999 Telex: 628425 fax: 01925 415961 DX 709290 GTN 7-21 X 1000
Ian Handyside Regional General Manager

Please let me know your thoughts on the well versus staff gauge issue, we may need to re-think our strategy somehow.

Yours sincerely

Alison

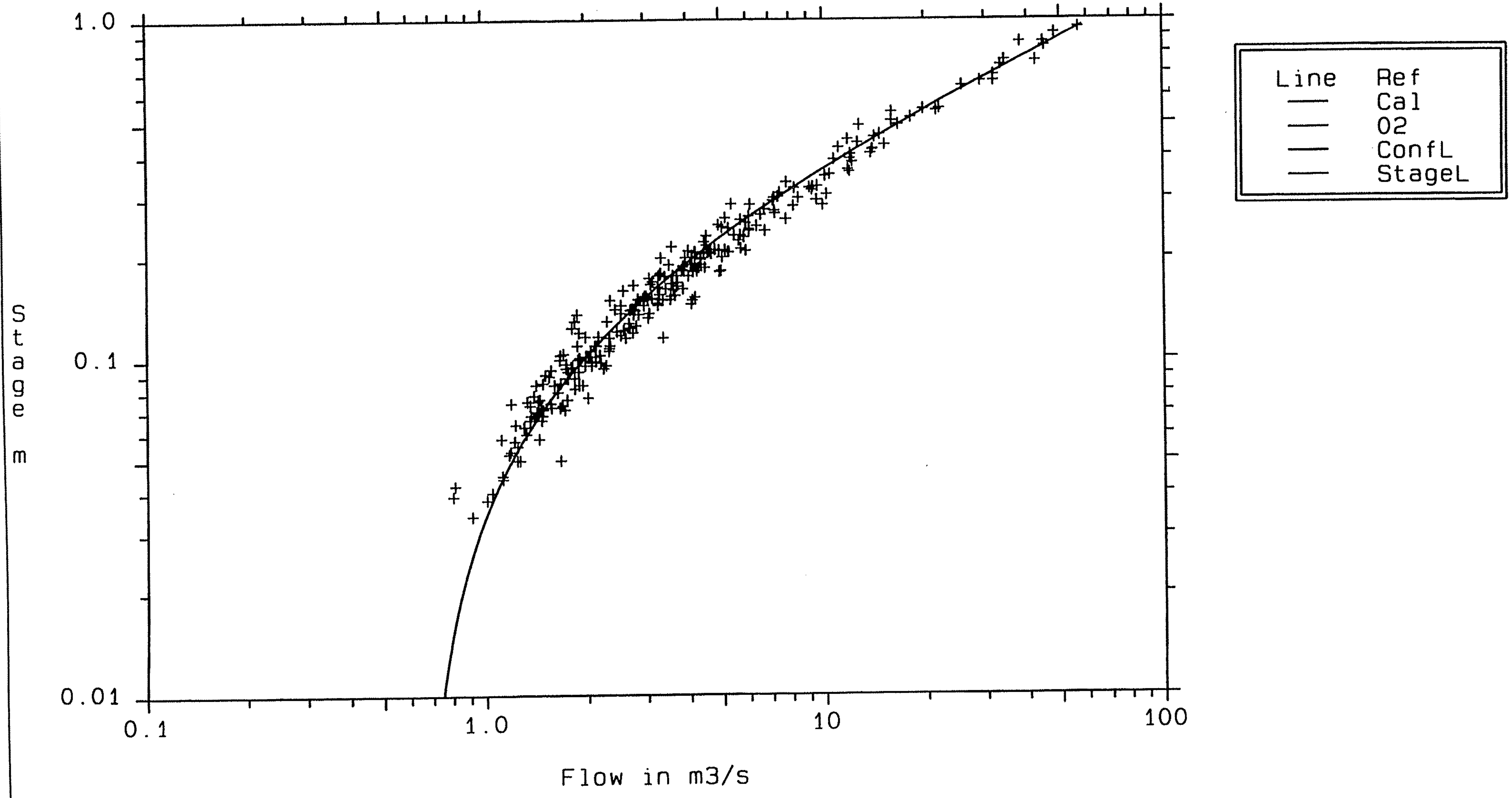
ALISON HANSON
Water Resources Officer (Hydrometric Information)

Encs

Please ask for

I:\WPWIN60\SWRTD00\DRSCOTWT.WPD

National Rivers Authority, North West Region.



SITE: BLACKFORD BR | REF: 690205 | GAUGEMAN (c) 1991-7 Hydro-Logic Ltd

```
Output by GAUGEMAN flow gauging management system  (C) 1990 Hydro-Logic Ltd
SUMMARY OF SELECTED GAUGINGS                 Printed on 23/01/1998 at 09:34 hrs.
-------------------------------------------------------------------------------


              National Rivers Authority,  North West Region.


-------------------------------------------------------------------------------
                       Primary  Station  Details
-------------------------------------------------------------------------------

Station Name    :  BLACKFORD BR          Station Reference :  690205
Watercourse     :                        N.G.R.            :  SD8069774

Location        :                        Gauge Zero height :   0.000 Metres
Structure       :  Non-Standard Control  Stage range:    0.033  to   0.942

Date 1st gauging 19/07/1976  last gauging 04/12/1997  No. of gaugings 269
Date 1st rating  11/09/1992  last rating  11/09/1992  No. of ratings  1

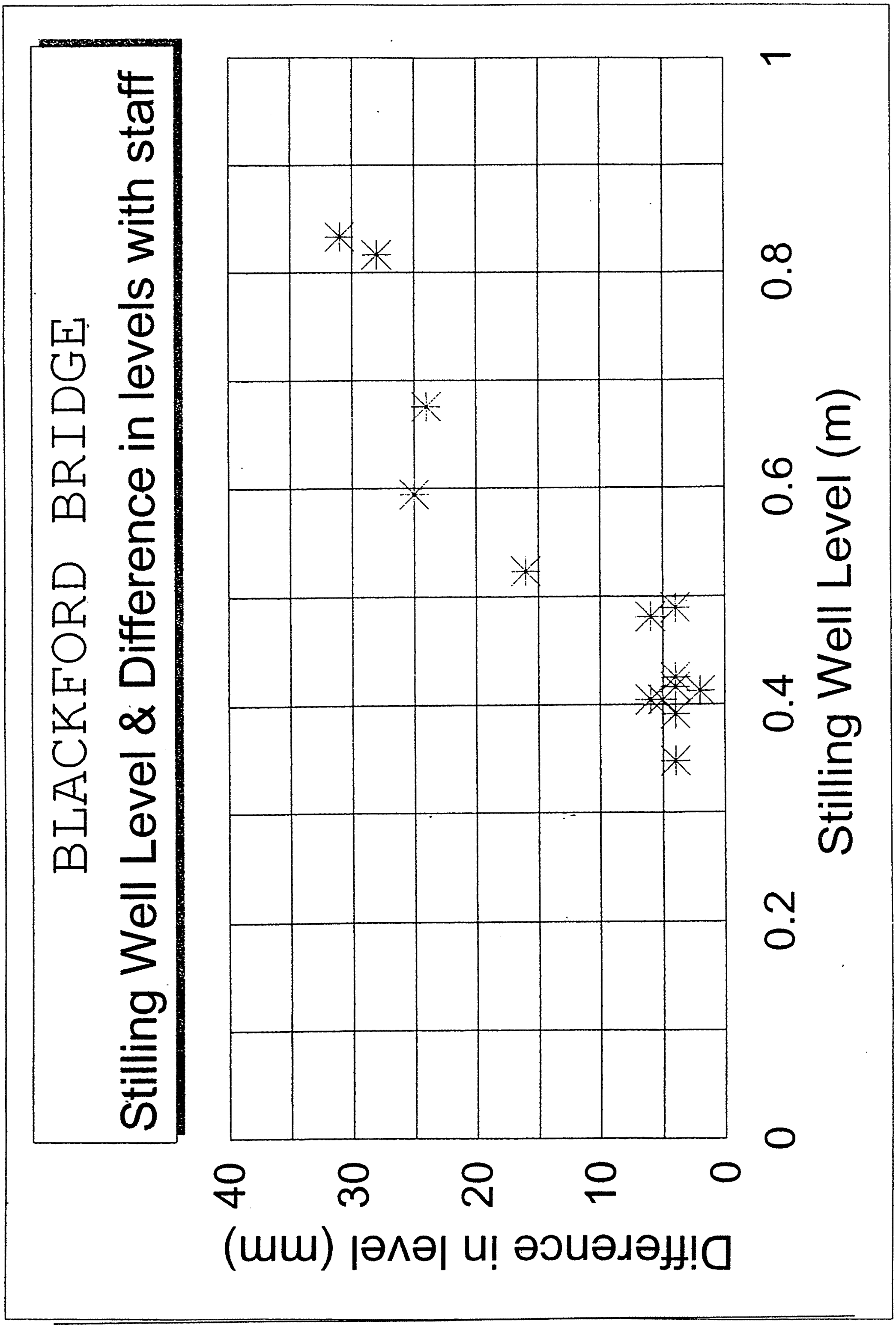
-------------------------------------------------------------------------------
                           Gauging  Details
-------------------------------------------------------------------------------
  Date      Time    Stage   Units   Variation   Area     Velocity   Discharge    X-Ref  Deviation   Observer
--------------------------------------------------------------------------------------------------------------
 30/09/78   12:00   0.639   Metres   Steady     0.0000    0.0000     25.7680      02      -4.51    ANO
 10/03/79   12:00   0.909   Metres   Steady     0.0000    0.0000     48.2220      02      -9.39    ANO
 11/03/79   12:00   0.831   Metres   Steady     0.0000    0.0000     45.1700      02       0.57    ANO
 11/03/79   12:00   0.942   Metres   Steady     0.0000    0.0000     56.9170      02      -0.06    ANO
 05/12/79   12:00   0.752   Metres   Steady     0.0000    0.0000     42.4890      02      15.05    ANO
 05/02/80   12:00   0.733   Metres   Steady     0.0000    0.0000     33.4540      02      -4.77    ANO
 11/03/81   12:00   0.856   Metres   Steady     0.0000    0.0000     44.6330      02      -6.02    ANO
 30/12/81   12:00   0.659   Metres   Steady     0.0000    0.0000     29.1560      02       1.89    ANO
 04/01/83   12:00   0.685   Metres   Steady     0.0000    0.0000     31.9180      02       3.58    ANO
 18/08/88   12:00   0.758   Metres   Steady     0.0000    0.0000     34.3660      02      -8.38    ANO
 08/12/93   13:20   0.660   Metres   Rising    26.4460    1.2061     31.8965      02      11.15    MES
 31/01/95   09:30   0.855   Metres   Rising    31.4000    1.2176     38.2312      02     -19.33    MES
--------------------------------------------------------------------------------------------------------------
```

BLACKFORD BRIDGE
CURRENT METER GAUGINGS

blakhead.wk4
23/01/98
pss

Information from Gauging Book, supplied by Mike Simpson 23 January 1998
(Gauging book does no go back further that earliest date given)

Date	Staff gauge	Stilling well	Difference	Stilling well	Discharge	Average	Discharge	Average
		/telegen	(mm)	average	(m3/s)	Difference	Squared	Difference
	Start	Start		level (m)		(mm)		(mm)
	End	End						
27/10/92	0.494	0.490	4	0.486	12.78	5.0	163	5.0
	0.488	0.482	6					
01/12/92	0.540	0.524	16	0.520	15.90	16.0	253	16.0
	0.531	NA	NA					
28/01/93	0.352	0.348	4	0.348	10.40	4.0	108	4.0
	0.352	0.348	4					
11/06/93	0.430	0.426	4	0.420	11.10	3.0	123	3.0
	0.415	0.413	2					
08/12/93	0.620	0.595	25	0.636	31.89	24.5	1017	24.5
	0.700	0.676	24					
05/01/94	0.411	0.405	6	0.411	13.90	5.0	193	5.0
	0.421	0.417	4					
20/01/94	0.410	0.405	5	0.399	12.01	4.5	144	4.5
	0.396	0.392	4					
31/01/95	0.845	0.817	28	0.826	38.20	29.5	1459	29.5
	0.865	0.834	31					

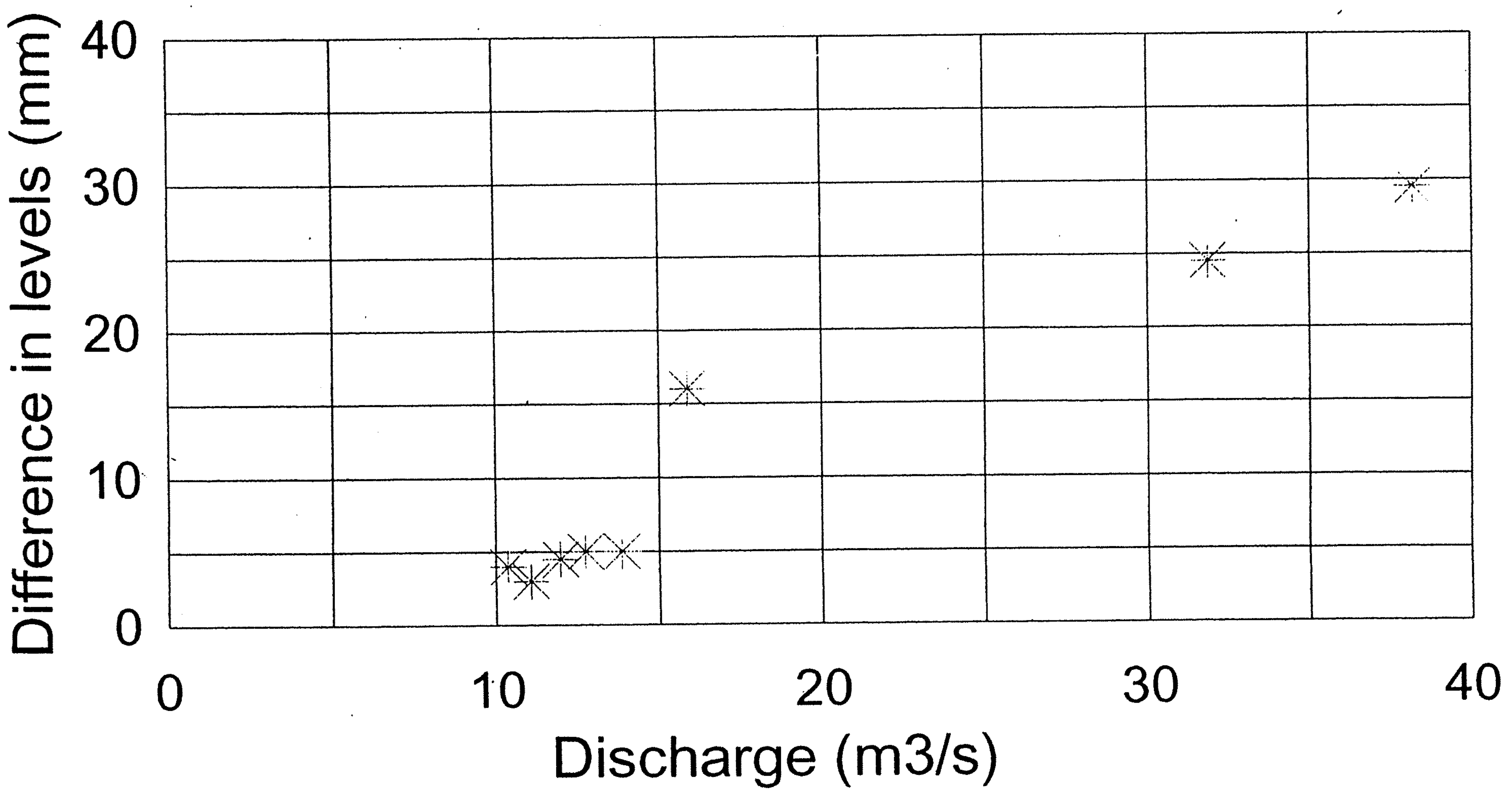


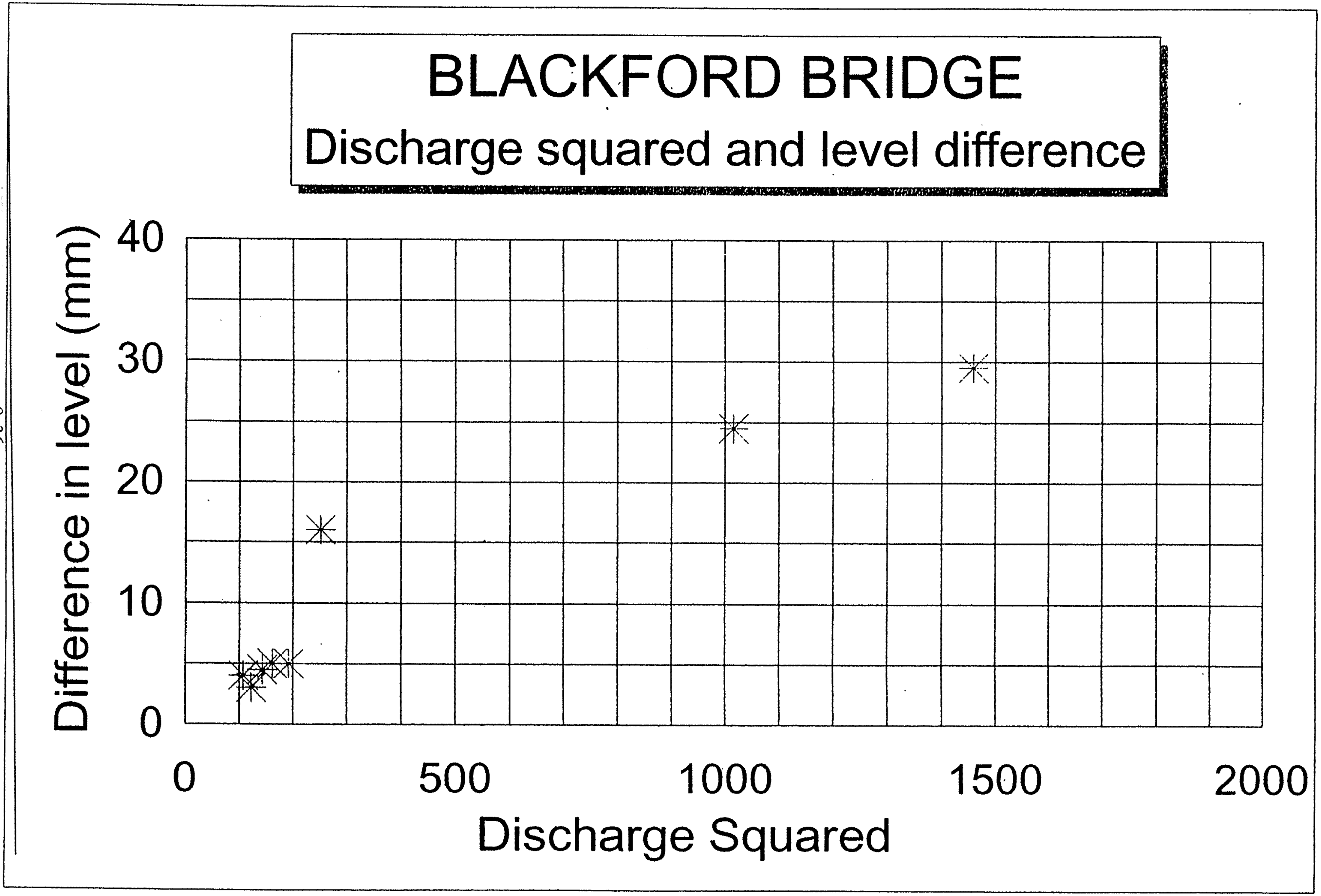
BLACKFORD BRIDGE

Stilling Well Level & Difference in levels with staff

BLACKFORD BRIDGE

Difference in level & Discharge




BLACKFORD BRIDGE
Discharge squared and level difference
Difference in level (mm)
40
30
20
10
0
0
500
1000
1500
2000
Discharge Squared

10 GREENHOLME SITE REPORT

1 INTRODUCTION

Greenholme gauging station is located on the River Irthing to the east of Carlisle and is used to measure flows from a 335 km^2 catchment which contains both upland moor and lowland arable farms. The 25 metre wide channel is rated by means of a cableway, and has an informal flat V low flow control which is approximately 50 metres downstream of the gauging station. The site was the first one to be selected for the project; the reasons for this choice include:

1. The station had an LF1, MF1, HF1 classification, indicating that good quality flow data are recorded by the Agency.
2. The station has an artificial control structure.
3. The station has a cableway u/s of the control that could be used to convey the transducer cables..
4. The site offered good security, with reasonable access.
5. It was possible to travel to the site within one hour of leaving base, thus maximising the chances of being on site during high flow conditions.
6. This was further enhanced by the fact that whilst Greenholme is an open channel river site which is relatively quick to respond due to the steep tributaries, the site which was to be studied at the same time (Low Nibthwaite) should be much slower to respond as it is below Coniston Water which will tend to attenuate any high flow events. Thus, when/if such events occur, we could travel first to Greenholme (< 1 hour) before moving on to Low Nibthwaite. This was an especially important factor for the first winter season when we intended to concentrate on evaluating the performance and limitations of the equipment.
7. Both Greenholme and Low Nibthwaite offered a large difference in channel width, with Low Nibthwaite falling on the border between the 1MHz and 500 KHz transducer requirements whilst Greenholme is a much wider channel.
8. High flows are generally contained within bank, although it has been known to occasionally flood in the past.
9. The site offered a wide range in stage, ensuring that different transducer configurations could be evaluated.

2 GAUGE INSTALLATION

The Greenholme gauge was installed on Tuesday 9 January 1996 by one technician from both Peek and SWS. Assistance was given by the Agency in transporting the equipment across the fields in a Landrover, and work commenced on site at 0900. By 1300 all equipment had been installed and cables connected; the 12 volt power supply was connected and all transducers were tested. Due to problems with EPROM installation by Peek (with the gauges using a Psion to log the data the EPROM specification had altered) it took almost two hours to commission the gauge, though this problem did not recur at Low Nibthwaite. Appendix A to this site report contains details of the gauge settings that were used at the site.

The gauge was installed with the downstream rack of transducers being placed on the far bank, downstream of the cableway which was used to support the co-axial cables on a catenary wire. The upstream rack was installed on the near bank upstream of the cableway, and the depth transducer was installed adjacent to the station steps. This is shown in Figure 2.1.

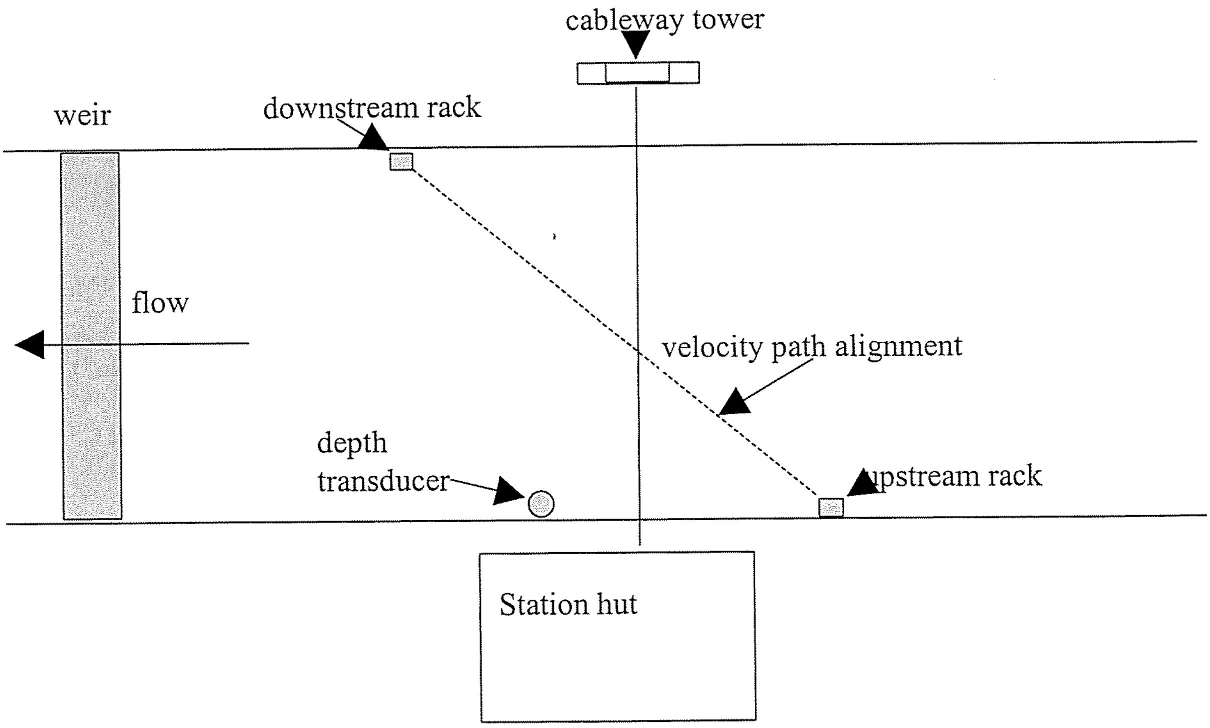


Figure 2.1 Schematic diagram to show the general layout of the gauge installation at Greenholme gauging station (not to scale).

One of the objectives of the installation with the Peek technician was to evaluate the need for an oscilloscope. At Greenholme it was found that the initial 'line of sight' alignment could not be improved by the 'scope.

The installation was completed by 1600, with all work being carried out under daylight conditions. A breakdown of total time spent on site for the preparation and installation work is as follows:

Initial site survey	6 man hours
Site preparation	12 man hours
Installation/commissioning	14 man hours
TOTAL	32 man hours

In addition to this a further three hours have been spent conduiting the cables and mounting the gauge within the station.

3 EVENTS RECORDED AT THE SITE

Unfortunately the period of study at Greenholme coincided with an exceptionally dry period, resulting in there being much fewer high flow events than would be expected in a 'typical' winter. Despite this data were recorded from all but one of the high flow events to be recorded at the site - the only event that was not recorded was a minor one which occurred a short time after the gauge had been installed, and which showed that the Psion data logger needed a more robust power source than the single 9v cell that the supplier had quoted. This was eventually adapted from a 12-volt car lighter socket adapter, available widely in motor factors and electrical stores.

Despite the very dry nature of the 1996 field season, a total of five medium-high flow events occurred at the site, and included a total range in levels of almost 1.3 metres. The transducers were operated at a total of five different levels during these events. Summary details of the five events and the corresponding transducer levels are shown in Table 3.1 overleaf.

Table 3.1 Details of timing and path configuration for the five events used for analysis from Greenholme.

Event	Start of event	End of event	Lower path level (m)	Upper path level (m)
1	0000 on 10/02/1996	0000 on 15/02/1996	0.088	0.388
2	0000 on 17/02/1996	0000 on 21/02/1996	0.088	0.488
3	0900 on 23/04/1996	1200 on 26/04/1996	0.088	0.588
4	2300 on 01/05/1996	2400 on 04/05/1996	0.088	0.588
5	0000 on 29/05/1996	2400 on 31/05/1996	0.188	0.688

4 GAUGE PERFORMANCE - RELIABILITY

The gauge generally worked well at Greenholme, yielding useful data despite the dry winter and spring. However, a number of problems arose due to both the instrument and site/location. Progress Report 3 described problems associated with the power supply, affecting both the gauge and data logger, which was overcome by using a larger power supply for the Psion as described above.

Sediment also caused problems with the gauge, in two ways. During high flow events, particularly after a prolonged dry period, suspended sediment loads appeared to be high in the river. The individual paths stopped working on a number of occasions at, or close to, the peak and then resumed operation when the river is falling. Whilst it cannot be proven that sediment is the cause, it is thought to be the most likely as it is usually the lower path which failed first. There were occasions when only the upper path failed, and this may be due to turbulence or aeration.

The second problem caused by sediment was due to the depth transducer becoming silted up during low flows. Fortunately, when this happened, the gauge automatically tries to fire both paths and so no velocity data were lost. The problem was quickly solved by raising and clearing the transducer..

The final problem experienced at Greenholme was due to a failure in one of the gauge components. This was first noticed during a routine site visit when neither transducer path was working. A total of four trips were made to try and resolve this problem, which was hindered by the fact that the river was too low to guarantee that the failure was not due to insufficient water cover. Alternative transducers were tried, and the transducers repeatedly realigned but to no avail. Eventually we managed to convince Peek that the problem was with the gauge itself and they despatched a spare transducer board. This was swapped with the old one (about 10 minutes work) and both paths restarted immediately. Peek have subsequently found that the failure was due to one of the resistors on the board having been incorrectly specified. It was working outside its specification when the gauge is running at 400 volts, and consequently failed. Peek have not known this to happen before, even when working at 600 volts, but have since upgraded the specification and asked us to return the Low Nibthwaite board when the gauge was removed so that they could upgrade it.

On a more positive note, when the new transducer board was installed we had to realign the transducer paths from scratch and reset the gauge configuration accordingly. Over the course of the project we developed an easy to use method of aligning the transducers on the racks using a pipe of the same external bore as the outside diameter of the transducers. This pipe is passed through the transducer block on the rack, allowing it to be used as a sight for aligning on the far bank rack. The task is made even more straightforward by sliding the transducer mounting plate to the top of the rack, and allows the whole operation to be carried out without having to get one's feet wet. Both paths were aligned in this way, and maximum counts were recorded on the first set of pulses. It is thought that the path alignment may be even better than that achieved using the oscilloscope with Peek as we have been able to operate the gauge with a lower gain (amplification) setting since the transducers were realigned, with no decrease in data return. If it is possible to minimise the voltage needed at a site where the channel is more narrow than at Greenholme, it should be possible to extend battery life and thus reduce the frequency of site visits.

Whilst adjusting the transducers during a high flow event at Greenholme it was noted that the gauge is less sensitive to path alignment in the vertical plane. This was found when raising the upstream transducers by an initial 200 mm, when it was found that maximum counts were still being recorded by the gauge. Due to the rapidly falling stage (the event was on 1/2 May 1996) it was only possible to raise the upper path by this amount before it was out of the water. However, the lower path was raised by a further 200 mm, giving a total vertical misalignment of 400 mm. Even at these settings the gauge was still giving maximum counts, and the velocities were between those of the upper and lower paths when operating in the horizontal plane. The recorded data are given overleaf in Table 4.1. It might be possible to set up the lower path along a vertical diagonal and leave the upper path at a much higher elevation to pick up velocities at the peak of high flow events. This offers even greater benefits when the weighting applied to the lower path velocities by Peek in the gauge software is taken into account.

Another observation that was made about the gauge performance is concerned with depth measurement. The gauge computes the depth of the water above the transducer using the velocity of sound in water calculated by the horizontal velocity paths. When the paths are not working (ie out of the water or have failed) the gauge uses the default setting of 1450 ms^{-1}. This results in the depth measurement being less accurate - typically up to 10 mm out. Whilst this is not too significant as the river flow is not being calculated when the paths are not working, it does have potential repercussions when the transducer paths become in range again. If the gauge is under-recording by 10 mm it will delay the path being recommissioned, causing minor data losses. One is able to overcome this potential problem by setting the minimum cover required for the transducers to work 10 mm lower than that found to be necessary.

Table 4.1 Data collected during the event of 1/2 May 1996 when the upstream transducers were raised 200 and then 400 mm above those on the downstream rack, before returning the transducers to their original levels. The data show that there may be scope for setting at least one of the paths up in this way.

Initial transducer settings at 0.088 and 0.588 metres above stage datum		
Stage	Upper Path Velocity	Lower Path Velocity
0.897	1.122	1.007
Both transducers raised by 200 mm on upstream rack		
0.894	1.133	1.025
0.893	1.133	1.030
0.891	1.131	1.027
0.890	1.119	1.027
0.887	1.117	1.024
0.885	1.130	1.023
Lower transducer raised by 400 mm on upstream rack		
0.882		1.035
0.883		1.031
0.882		1.031
Transducers set to initial settings		
0.873	1.081	0.978
0.874	1.085	0.984
0.873	1.080	0.982

During a routine site visit we noted that the upper transducers were just breaking the surface of the water. As the minimum depth from the centre of the transducer to the surface is, in theory, 0.213 m, the path had been decommissioned by the gauge. We reduced the minimum cover parameter on the gauge to recommission the path and found that it was still giving maximum counts. Whilst it must be remembered that this was carried out at low flow conditions, when the water surface was smooth it did demonstrate that when correctly aligned the minimum cover required is much less than the theoretical value. We have thus been operating the gauges with the minimum cover set at 50 mm.

5 GAUGE PERFORMANCE - FLOW MEASUREMENT

Much of the analysis carried out on the Greenholme data sets is contained in Chapters 4 and 5 of the Environment Agency R&D Technical Report W189 which accompanies this Project Record. This site report will thus concentrate on the data that were recorded, introduce the analysis that was undertaken, and summarise the results that were obtained from the site.

When carrying out the data analysis we tried to bear in mind the practicalities of running a hydrometric network, along with the likely applications that the gauges might be used for. We considered that the potential uses to fall into two distinct categories:

1 Using the gauges to establish a 'ball park' estimate of peak flow. Such a use might be the calibration of a hydraulic model. The time available to collect the data might be very limited, possibly including only one event, so it will be necessary to configure and use the gauge to ensure that reasonable estimates of flows are obtained in as short a length of time as possible. (Chapter 4 in the Technical Report)

2 The gauges might be used to establish a stage-discharge relationship for a gauging station, be it a new one or one that has not been previously gauged. The time available for this might be longer, say over a six or twelve month period, but the accuracy of the output will need to be higher to ensure that the additional time spent by the hydrometric staff will be of benefit. (Chapter 5 in the Technical Report)

Each of these approaches will be addressed in turn.

5.1 Using The Gauge To Calibrate A Single Event

The flows recorded by the gauge and the Agency for each of the five events listed in Table 3.1 were plotted as time series, and their differences analysed to see if there was a consistent pattern or cause. For the purposes of this Site Report one of the events (event 1) will be used to demonstrate the analysis that was completed - this was the biggest single event to occur at the site during the study period.

When the gauge was installed at Greenholme it was configured with the default settings. Specifically, the mean bed level was set at that which was surveyed along the velocity path, and the bed correction factor was set at 0.8. The depth data recorded by the equipment has been used to derive the flows rather than that collected by the Agency as there was very little difference between the two for this site.

When analysing the data from the events at Greenholme it quickly became apparent that, regardless of the levels at which the transducer paths were deployed, the gauge consistently produced higher flows for a given stage than the Agency rating. If it is assumed that the gauge is working properly, the flow is parallel to the banks and the path length and levels had been accurately surveyed, there were two possible explanations for this:

1. The mean bed level was too low, resulting in the cross-sectional area of the channel being overestimated, or
2. The bed correction factor was too high, and that in reality the velocities in the lowest 'slice' were less than 80% of those recorded by the lowest velocity path.

The channel cross-section at Greenholme was far from uniform, with a sandstone ledge lying a short height under the water surface. Following advice from the gauge manufacturer, it was initially decided to adjust the mean bed levels to see how this would account for this. Whilst it was possible to retrospectively optimise this parameter by using data collected during the whole event, it was felt that a more realistic approach would be to try and adjust the level using data that might reasonably be available to the technician installing the equipment.

It was therefore assumed that, if no flow data were available for a site, it would be possible for a gauging to be undertaken at the same time as the gauge was being installed or commissioned. In order to represent this it was assumed that the first flow value from the Agency rating would reflect the derived flow from the gauging, and the mean bed level was thus adjusted to produce a flow that was as close to the first corresponding Agency flow value.

This meant that the mean bed level was adjusted from -0.47 metres to -0.32 metres, resulting in the first flow value from the gauge being reduced from 4.55 to 3.94 cumecs, compared to the Agency value of 3.924 cumecs. As the transducer path had been installed in the deepest possible channel section (to enable the transducer paths to be operated at as wide a range of levels as possible) this adjustment appears to be physically reasonable.

Figure 5.1 shows the Agency, gauge and adjusted gauge flows recorded at Greenholme between 0000 on the 10th February 1996 and 0000 on the 15th February. Figure 5.2 shows the percentage difference between the Agency flows and those calculated by the gauge with both default and adjusted bed level parameters.

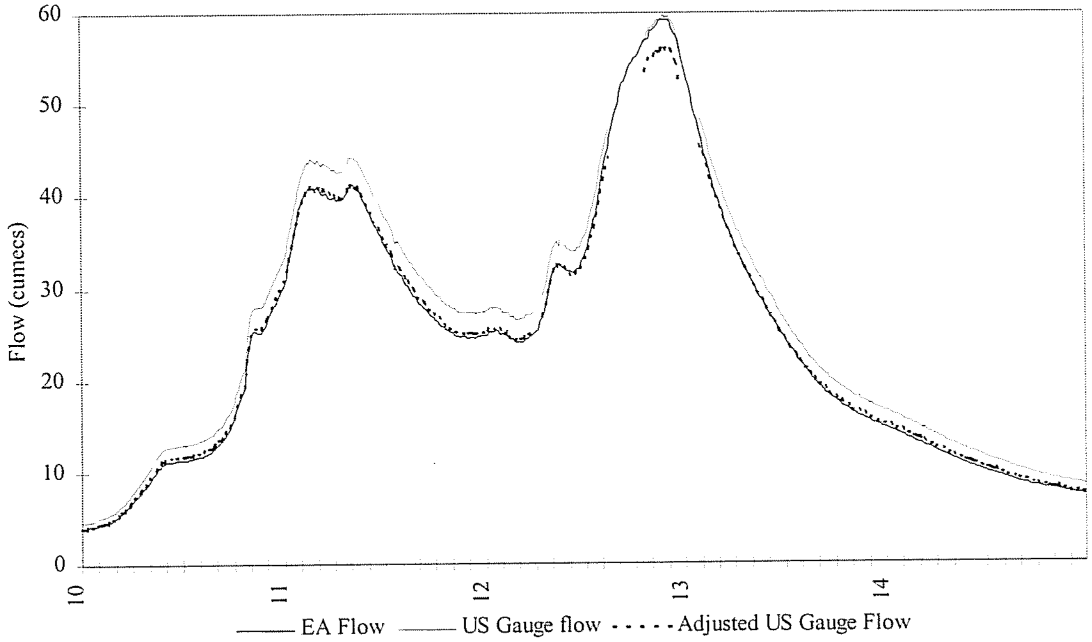


Figure 5.1 Agency, gauge and adjusted gauge flows at Greenholme between 0000 on the 10th and 0000 on the 15th February 1996. The transducers paths were deployed at 0.09 and 0.39 metres above stage datum, and the maximum stage during the event was 1.317 metres. Tick marks are at two hour intervals.

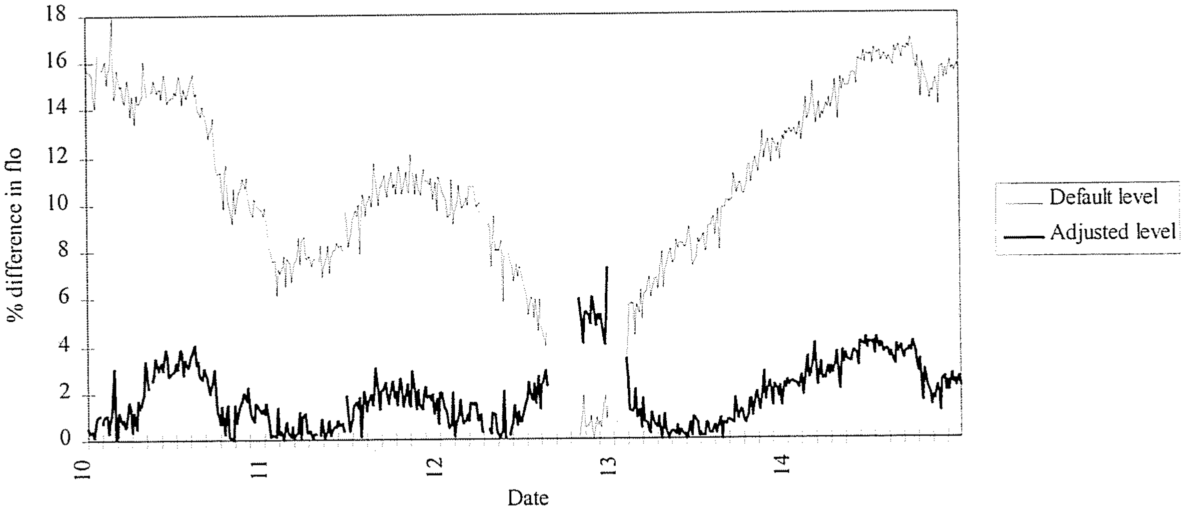


Figure 5.2 Percentage difference between flows calculated by the Environment Agency rating for Greenholme and those produced by the ultrasonic gauge using both the default and adjusted mean bed levels between February 10th and 15th 1996

From these data it can be seen that whilst the gauge performs reasonably well with the default settings, its performance is dramatically improved by adjusting the mean bed level solely on the basis of the first flow value. For the first event the mean difference in flows derived by the Agency rating and the gauge falls from 8.07% to 1.45 %, with the maximum difference being just 6% during the peak flows. If it is considered that, at this time, the highest transducer path was almost 1 metre below the water surface, and one of the transducer paths had failed (the lower one) during the higher flows, this 6% difference can be both understood and explained.

It can also be seen from Figure 5.1 that the gauge failed to function during part of the event. Close analysis of the data reveal that the lower of the two velocity paths failed for approximately 40% of the total duration, whilst the upper path failed for approximately 6 hours, or 5% of the event. This was the first event to occur in the catchment for almost twelve months, and neighbouring fields had been recently ploughed prior to planting. Given this it is likely that sediment loads, be they suspended or saltated, will have been high, and it is felt that this is the reason why the velocity paths failed.

The analysis was repeated for all five events, and the results are summarised in Table 5.1 below, from which the improvement can clearly be seen.

Table 5.1 Summary results of the analysis carried out on the data collected during the five high flow events at Greenholme over the period January - May 1996. The % data refer to the mean difference between the Agency and gauge flows for the event using the appropriate gauge settings.
Initial adjusted bed level - the value determined from the first flow value of the first event.
Event specific bed level - the value determined from the first flow value of the individual event to which the analysis relates.

	Event 1	Event 2	Event 3	Event 4	Event 5
Q Mean (cumecs)	24.64	14.14	11.44	8.07	9.54
Q Max (cumecs)	59.27	49.42	19.79	29.77	30.24
Height of low path (m)	.088	.088	.088	.088	.188
Height of high path (m)	.388	.488	.588	.588	.688
Default gauge bed level	8.07%	13.31%	5.05%	8.66%	5.75%
Initial adjusted bed level	1.45%	1.76%	6.04%	4.27%	4.23%
Event specific bed level		1.55%	1.05%	2.55%	1.09%

At the Project Progress Meeting held in July 1996 considerable time was spent discussing the merits of altering the bed level during low flow events to fine tune the gauge, as recommended by Peek, or adjusting the correction factor used to reduce the velocity in the lowest panel. It was decided to explore this further using the data collected at Greenholme. The same five events that were used for the work detailed in Progress Report 3 were used for this analysis. A simple model was created and operated as follows:

1. The optimum bed level was set using only the first four observations recorded by the gauge once the river had started to rise, representing data collected during the first hour of an event, with the reduction factor being set to the Peek default value of 0.8. This bed level was then used to calculate the flow for the whole event. The optimum level was identified by minimising the difference between observed and calculated flows, both in absolute and % terms. For methods three and four these often produced slightly different results (due to positive and negative differences) in which case the % difference factor was used;
2. The reduction factor used to apply the velocity recorded over the lowest path to the lowest panel was optimised using the same method, on the first four observations. The bed level was set to that measured during the initial channel survey;
3. The bed level was then optimised using data collected over the whole event, ie with the benefit of hindsight;
4. Similarly, the reduction factor was optimised using the complete data set.

The results of this analysis are summarised below in Tables 5.2 to 5.5:

Table 5.2 Summary results obtained from optimising the bed level using only the first four observations

Event	Bed Level	Mean difference in flows (cumecs)	Mean % difference in flows
1	-0.32	0.401	1.84
2	-0.29	0.198	1.40
3	-0.33	0.597	5.06
4	-0.39	0.202	4.19
5	-0.36	0.247	2.20
Mean		0.329	2.938

Table 5.3 **Summary results obtained from optimising the reduction factor using only the first four observations**

Event	Reduction factor	Mean difference in flows (cumecs)	Mean % difference in flows
1	0.41	0.900	3.19
2	0.32	0.184	1.24
3	0.46	0.572	4.85
4	0.65	0.186	3.87
5	0.60	0.235	2.06
Mean		0.415	3.042

Table 5.4 **Summary results obtained from optimising the bed level using data collected during the whole event**

Event	Bed Level	Mean difference in flows (cumecs)	Mean % difference in flows
1	-0.30	0.395	1.33
2	-0.30	0.116	0.750
3	-0.38	0.106	1.05
4	-0.36	0.169	2.29
5	-0.38	0.131	1.67
Mean		0.171	1.30

Table 5.5 **Summary results obtained from optimising the reduction factor using data collected during the whole event**

Event	Reduction Factor	Mean difference in flows (cumecs)	Mean % difference in flows
1	0.44	0.799	0.316
2	0.36	0.115	0.732
3	0.63	0.105	1.06
4	0.57	0.166	2.36
5	0.65	0.117	1.05
Mean	0.53	0.259	1.68

From these data it can be seen that there is little to choose from either method, and that both methods would appear to give an acceptable performance, the mean average percentage difference between observed and calculated flows being no more than 3.05% by any method, and less than 5.1% for any individual event. It would appear that adjusting the bed level gives marginally better results when the methods are compared over the five events as a whole, but it must be noted that this approach also gives the highest errors for single events. Additional observations are that the mean bed levels appear to fall within a narrower range than the reduction factors, and that all the reduction factors are significantly less than the 0.8 value used by Peek in their software.

Whilst these results demonstrate that the gauge can produce acceptable results when operated in a number of different ways, it is important to remember that if a general, simple approach can be established that does away with the need for calibration or optimisation of specific parameters, this will significantly help the Agency in using the equipment at a wide variety of sites with different personnel as it will allow a consistent procedure to be followed. With this in mind the model was re-run for the five different events, using the mean bed level or reduction factor as appropriate. The results from this are given in Table 5.6.

Table 5.6 Summary results obtained by using the average mean bed levels and reduction factors from the four different methods and applying them to the five individual events.

Method 1, mean bed level -0.34	Event1	Event2	Event3	Event4	Event5	Mean
Mean difference in flows	0.621	0.439	0.487	0.267	0.436	0.450
Mean % difference in flows	3.27	3.94	4.11	2.87	4.36	3.71
Method 2, reduction factor 0.53						
Mean difference in flows	0.656	0.445	0.478	0.262	0.592	0.811
Mean % difference in flows	3.21	4.03	4.04	2.83	6.17	4.06
Method 3, mean bed level -0.34						
Mean difference in flows	0.621	0.439	0.487	0.267	0.436	0.450
Mean % difference in flows	3.27	3.94	4.11	2.87	4.36	3.71
Method 4, reduction factor 0.49						
Mean difference in flows	0.613	0.587	0.352	0.201	0.462	0.440
Mean % difference in flows	3.51	5.25	2.99	2.41	4.66	3.76

From these results it can again be seen that adjusting the mean bed level would appear to be the better of the two approaches, particularly as the average of the five mean bed levels is the same for both methods 1 and 3. It can also be seen that using the mean bed level obtained from only the first hour's data for each event gives marginally better results than setting the reduction factor from the complete data sets for all events.

Finally, it must be remembered that whilst these results are valid in their own right, the fact that only very minor differences in performance exist between the different methods does not allow us to make any early conclusions about which method should be adopted for general use. This is especially so when it is further remembered that the flows at Greenholme were not particularly high.

It was thus decided to continue to collect velocity data from the gauge at the four remaining field sites, and operate the gauge in the 'default' mode initially. This showed that there was still little to choose between the two approaches. As the mean bed level can be surveyed, and thus input as a parameter rather than regarding it as a variable, it was eventually decided to 'optimise' the bed correction factor when deploying the gauges.

5.2 Using The Gauge To Derive A Stage Discharge Relationship

Multi-path ultrasonic gauges determine the channel discharge by splitting the channel cross section into many vertical panels, each with a transducer path running through the centre. At the start of the project we stated that we thought it would be possible to use the two paths of the 1408 to replicate this by operating the transducer paths at different levels for different events, and by using the collected data to derive **stage-velocity** relationships for each path level. These relationships could then be used to derive a stage-discharge relationship using the same principles as the multi-path gauges. It was noted after just one event that the relationship between stage and velocity at Greenholme appeared to be the same during both rising and falling levels, suggesting that the approach had potential.

Having operated the Greenholme gauge at a total of six different path levels we determined a stage velocity relationship for each of these paths. As this was an exploratory exercise it was decided to derive the relationship using simple linear relationships, though it is realised that these may not be the most suitable method at higher stages. Six relationships were derived using this method, and they are given in Table 5.7.

Table 5.7 Best fit lines derived for stage-velocity relationships for the transducer paths at Greenholme using the data collected between January and May 1996.

Path Level	Best Fit Linear Regression Line	R^2 value
0.088	V = 1362.8 stage - 213.03	0.9986
0.188	V = 1465.6 stage - 265.2	0.9989
0.388	V = 1442 stage - 210.67	0.9958
0.488	V = 1532.2 stage - 275.97	0.9991
0.588	V = 1631.1 stage - 337.52	0.9851
0.688	V = 1755.5 stage - 265.2	0.9989

These relationships are plotted below in Figure 5.3.

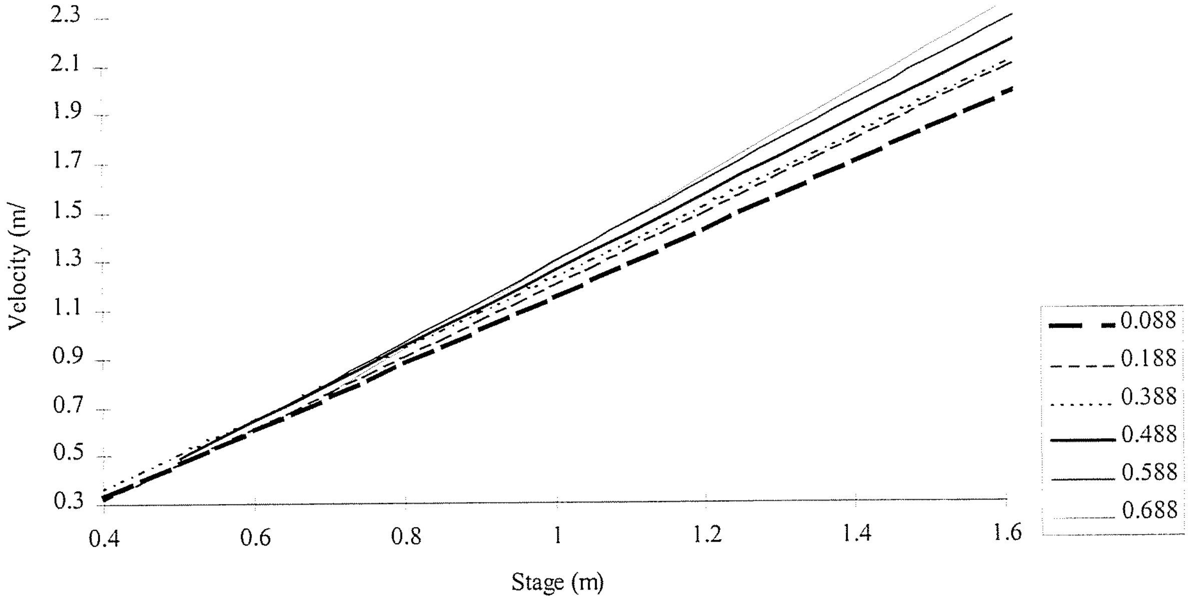


Figure 5.3 Stage velocity relationships derived for the six transducer path levels at Greenholme

It can be seen from Figure 5.3 that the stage velocity relationships form a consistent pattern for the different velocity paths, with higher velocities being produced for the higher paths at a given stage. Whilst this is to be expected, the data plotted in Figure 5.1 in the Technical Report show that in some cases, most notably the 0.688 m path, the relationships are based on very limited data (in this case, 23 data points collected between a stage of 0.7 and 0.9 metres) and are still able to form a relationship that is consistent with data collected over a much wider range. The same observation was also made of the Blackford Bridge and Middleton in Teesdale data. This would suggest that if data are collected from at least one velocity path over a wide range in flows, this will provide a suitable reference to which relationships from less comprehensive data sets at other levels can be compared and, if necessary, adjusted at the higher levels, thus reducing any uncertainty associated with the extrapolation of the relationships. The fact that the 0.688 metre path relationship was derived from only 23 data points, relating to less than eight hours during the event, and is still able to produce a relationship that is consistent with those collected over a much wider range in levels would suggest that the need for any adjustment may be small.

The six relationships contained in Table 5.7 were then used to derive a stage discharge relationship for the channel section using the same method as the multi-path gauges, in the following sequence:

1. For a given river level the number of velocity paths that would be immersed was identified.
2. For each of the individual velocity paths that were immersed the velocity was derived using the appropriate stage-velocity relationship.
3. Q_s, the discharge for each vertical slice in the river, is then calculated using the derived velocities.
4. The total discharge for the given river level is then obtained by summing the various values of Q_s.
5. This process was repeated for different river levels at a 5 mm increment to produce the stage-discharge relationship.

The resulting relationship is plotted in Figure 5.4, which also shows Rating 08 used by the Agency for the past twenty years, along with the rating that was approved for use mid-way through the study period in March 1996. The rating curves have all been taken up to a maximum stage of 2.0 metres, yet the peak observed level was only 1.32 metres.

From these it can be seen that the 6-path derived relationship performs especially well when compared to Rating No 08 which was used by the Agency for so long. It performs particularly well at stages up to 1.5 metres, never differing by more than 5%. Even at the two metre stage the deviation is less than 7% which is quite impressive if one remembers that the highest transducer path was only at 0.688 m.

However, the performance is less impressive when compared to the newly revised rating. Whilst it again performs well up to the 1.5 m level, above that it begins to depreciate significantly with the deviation being over 30% at the 2 m level. It must also be noted that Rating 08 also behaved in a similar way, clearly visible in Figure 5.4, and if the new Agency rating is extended to above three metres it becomes concave once more, eventually rising to meet the two upper curves.

This analysis is extended further in Chapter 5 of the Technical report.

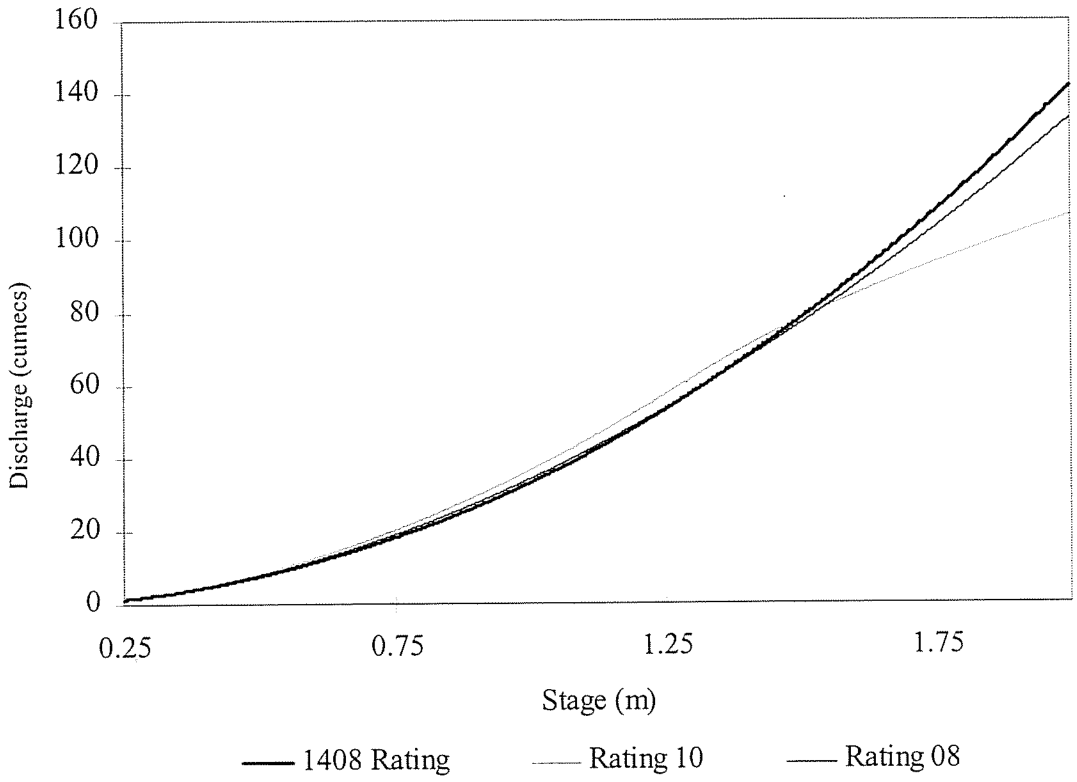


Figure 5.4 The rating curves derived by the stage-velocity method from the ultrasonic gauge (1408 Rating), the curve used by the Environment Agency between 1975 and 1996 (Rating 08) and the most recent Agency curve (Rating 10) for Greenholme gauging station.

To try and put the derived relationship into some kind of perspective we looked for the highest recorded flow over the whole monitoring period, and compared the value calculated by the gauge derived relationship to that given to us by the Agency. The Agency peak flow of 59.269 cumecs compares most favourably to the gauge's derived value of 59.268 cumecs, a difference of less than 0.002%! It can thus be seen that when the relationship is applied to the same range of flows over which the data were collected it is able to perform very well. Further analysis, involving the use of non-linear best fit lines, may improve this performance even more. It is most encouraging to note that the gauge was able to perform within 5% of the rating used by the Agency since September 1975 after only five months' use.

6 SUMMARY

It is perhaps to be expected that the first site to be studied is the one that has the greatest potential to provide answers to some of the issues that the project was to address, and it appears that despite the disappointingly dry nature of the period the studies at Greenholme were most fruitful. The following list provide a summary of the results arising from the studies at Greenholme (those marked with a * were later confirmed at other sites):

- The viability of a 12v power supply was established, together with using the Psion as a datalogger.*
- Assessment of typical deployment times and costs.*
- Assessment of aerial routing of cables.*
- Confirmation that the gauge works in rivers of >25 metres width.
- Assessment of our method of mounting the transducers.*
- Assessment of lining up the transducers by eye.*
- Confirmation that the gauge works under varying flow conditions, albeit with some potential problems at high levels, thought to be due to high suspended sediment concentrations.*
- Identifying the main source of uncertainty in the derived flows, and demonstrating a way of reducing this by 'optimising' the bed correction factor.*
- Confirmation of extrapolating the gauge results over a limited range, but because of a lack of high flow events, we were not able to monitor beyond the 'break-point' in the stage discharge relationship.
- Problems with gauge performance due to a variety of reasons, most notably the power supply.*
- Problems with the depth transducer silting over.
- Problems with the design of some of the gauge components.*
- There is potential in deploying at least one of the paths in a diagonal alignment (relative to the horizontal) but, as with many of the results, this has yet to be confirmed.
- Problems with the depth measurement if both velocity paths are out of the water, due to an assumed velocity of sound.
- The minimum cover recommended by Peek for each of the velocity paths can be significantly reduced (by as much as 90%) given suitable channel conditions.*
- A methodology for deriving a stage-discharge relationship was derived, although this had still to be tested for another site.

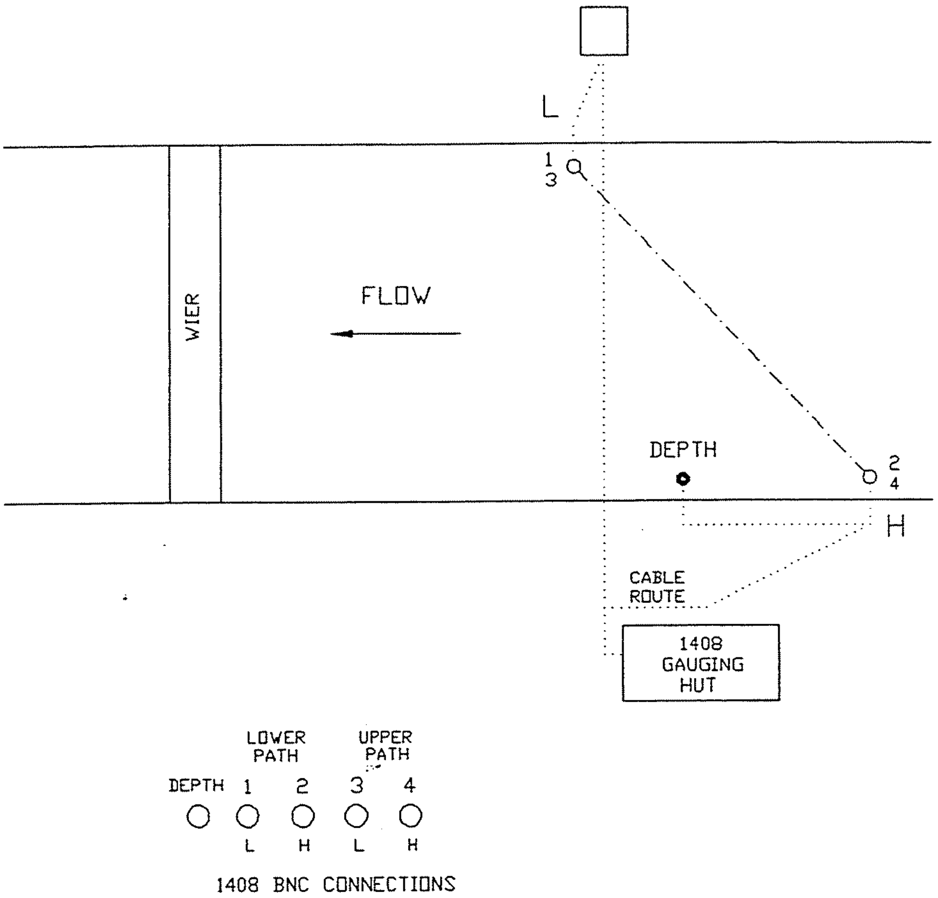
APPENDIX A
Gauge settings for Greenholme

CONTENTS

1. SITE DATA

Number of velocity paths	2
Number of ultrasonic depth paths	1
Number of auxiliary depth gauges	0
Auxiliary depth gauge type	-
Transducer details	Incastec 500 khz, 50mm
Power supply	12v d.c. Dryfit Battery
Output Cards	None

1.1 Path Configuration



2. PROGRAMMED DATA

2.1 Operational Data

GENERAL DATA

Path Configuration	: In Line
Height Reference	: A.O.D.
AOD of Mean Bed Level	: -0.430 Metres
AOD of Aux Depth Zero	: N/A
Flow Units	: Cumecs

DEPTH DATA

Transducer Height	: -0.326	Metres
Calibration Coefficient	: 1	
Maximum Height	: 4.0	Metres

VELOCITY DATA		Path #L	Path #H	
Transducer Height	:	0.088	0.388	Metres
Path Length	:	31.46	31.46	Metres
Calibration Coefficient	:	1	1	
Angle to Flow	:	45	45	Degrees

2.2 Preset Data

GENERAL DATA

Aux. Depths Status	: 0=16 1=16 2=16 3=16
No. of Vel. Paths	: 2
Ring Test Time (μS)	: 256
Vel of Sound	: 1427.19 (Calculated by system)
Minimum Cover (M)	: 0.213

DEPTH DATA

Address	: 129
Identifier	: 127
Depth Identifier	: 255
Existence	: 0 (Changed by System)
Minimum Depth (ms)	: 0.25

VELOCITY DATA		Path #L	Path #H
Address	:	130	131
Delay L (μS)	:	4	4
Delay H (μS)	:	4	4
Maximum Time Diff	:	2	2
Certification	:	0	0

2.3 Time & Output Data

Site Reference Number : 1234

Analogue Output Values

Maximum Flow : 0
Maximum Depth : 0
Minimum Flow : 0
Minimum Depth : 0

2.4 Velocity Factor Tables

When installed all 4 tables were set up with the level multipliers set to 1, and the bottom section multiplier set to 0.8. The tables will be configured when sufficient velocity profile data has been obtained for the site.

3. TRANSDUCER BOARD - Configuration

Velocity Transducer EHT= 400 Volts	Link 1 Link 2 Link 3 Link 4 Link 5	Open Closed Open Off On
Depth Transducer Voltage +15 volts	Link 9	+ 15v
Amplifier Gain = 40 dB	Switch 1/1 Switch 1/2 Switch 1/3 Switch 1/4 Switch 2/1 Switch 2/2 Switch 2/3 Switch 2/4	On On Off Off Off Off Off Off
-1 Volt Condition True	Link 6	Removed
Amplifier O/P Polarity -ve 1st	Link 7	Top position

4. DATA OUTPUTS

4.1 RS232 Output

This uses the same interface as the GCP communication, to provide log information suitable for a Psion organiser.

Header Record : - sent on power up and at 9 o'clock every day
(to check the correct time stamp)

- format
  - <H> - ASCII H for header identifier
  - hh - time, 2 digits of hour
  - mm - time, 2 digits of minutes
  - <,> - comma separator
  - dd - date, 2 digits for day of month
  - mm - date, 2 digits for month
  - <cr> - ASCII carriage return
  - <lf> - ASCII line feed

Data Record : - sent every 15 minutes (all 1 minute values)

- format
  - <D> - ASCII D for data identifier
  - hh - time, 2 digits of hour
  - mm - time, 2 digits of mins
  - <,> - comma separator
  - ffffff - flow, 6 digits (decimal point implied)
  - <,> - comma separator
  - dddd - depth, 4 digits (last 4 digits of display)
  - <,> - comma separator
  - vvvv - velocity L, 4 digits (last 4 digits of display)
  - <,> - comma separator
  - vvvv - velocity H, 4 digits (last 4 digits of display)
  - <cr> - ASCII carriage return
  - <lf> - ASCII line feed

<u>Example</u>

H1035,0712	- power up header - 10:35 hrs, date 07/12
D1045,001234,5678,0123,0234	- data - time 10:45 hrs, flow 1.234 cumecs, depth 5.678m, vel L 0.123m/s, vel H 0.234m/s
D1100,-01236,9863,-102,-103	- data - time 11:00 hrs, flow -1.236 cumecs, depth 9.863m, vel L -0.102m/s, vel H -0.103m/s
H0900,0812	- 9 o'clock header - 09:00 hrs, date 08/12
D0900	- data record for 0900 hrs (same format as above)

The 1408 assumes GCP is connected unless 'pin 5' is high when it recognises that the Psion is connected. The Psion automatically sets this pin high. The cable connections between the 1408 and the Psion are:

1408	Psion
2	2
5	5
7	7

11 LEA HALL SITE REPORT

1 INTRODUCTION

Lea Hall gauging station is located at the base of the Aldford Brook catchment, a short distance upstream of its confluence with the River Dee. The site has a 3 metre wide crump weir with the concrete retaining walls extending some 2.6 metres upstream before turning into the bank. Typical stages at the site due to the Aldford Brook itself are between 0.05 and 0.6 metres. However, despite this narrow range, the stage often exceeds 1.2 metres due to the River Dee backing up. Whilst the station is some 15 km upstream of Chester weir the crest of the weir is only 300 mm above the Chester weir crest. Non-modular flows are thus caused by both high flows and high tides.

The river channel has a completely flat concrete bottom some 500 mm below the weir crest, which would hopefully help to resolve the issue of whether or not the bottom fraction or bed height should be adjusted when setting up the gauge. The approach channel is reasonably straight for approximately 50 metres upstream of the wing walls, but beyond this it is essentially a sustained and gentle curve.

The Welsh Region offered (and provided) to issue telemetry alarms from the station, and to undertake gauging work during high stage events to evaluate the gauge performance. They also offered to note the gauge status when on site, and to advise of any problems or faults that may arise. The station was chosen as a suitable study site as it was intended that the following issues would be addressed:

- It was anticipated that the presence of a British Standard structure would enable good quality 'true' flow data to be available.
- Evaluate the ability of the gauge to work in a very narrow channel with a limited flow range.
- Confirm the 1995/1996 findings that a stage discharge relationship can be derived using a series of stage-velocity relationships.
- Try and resolve the issue of altering bed level or bottom section multiplier when determining channel discharge from the two-path velocity data.
- Look at the potential issue of u/s pooling of water below the level of the weir crest.
- Assess the performance of the gauge under eccentric non-modular conditions caused by backing up from a downstream source.

- Confirm that both the 500 KHz and the 1 MHz transducers work under these conditions (we experienced problems at Low Nibthwaite during 1995/1996).
- Possibly explore the use of reflector systems, depending on time and flow conditions;
- Given that non-modular conditions will either exist for sustained periods (high flows in the Dee) or at predictable times (high tides), determine how much useful data can be collected during such events by altering the level of the transducers.
- There was a doppler shift flow gauge installed at the site - would this affect the performance of the 1408 gauge?

2 GAUGE INSTALLATION

The Lea Hall gauge was installed on 31 October and 1 November. The installation took a total of 22 man hours to complete from arriving on site on the Thursday to departing on the Friday. At least three hours were spent trying to overcome a fault that had developed with one of the circuit boards on the instrument before it was decided to use the other instrument and return the gauge to Peek for inspection - it was found to be faulty. Transducer counts were typically 230 (out of a maximum 255) when the gauge was initially installed, lined up using our pipe method, but increased to 255 once the suspended sediment decreased as the water had cleared (velocities were as low as 2 cm s^{-1} as the river had backed up).

Four transducers have been installed on two racks, the downstream rack being positioned just upstream of the approach slope to the weir crest on the right bank. The racks were mounted within the confines of the concrete channel, resulting in the transducers being aligned some 50^0 to the flow. The installation was carried out with a view to evaluating the reflector system at this site, which is why the downstream rack was so close to the weir. A schematic diagram of the site layout is shown in Figure 2.1.

One early 'result' was obtained during the actual installation process, a result which explained the poor performance of the depth transducer at Low Nibthwaite earlier in the year. The depth transducer worked fine when the gauge was running off the 12v external supply, but it was observed that as soon as the battery was put on to a trickle charge the background noise caused by the charger corrupted the signal from the transducer. This problem was overcome by operating the gauge off the mains supply, keeping the external 12v batteries connected as a backup should a power failure occur. Peek were unaware of this problem (they supplied the battery charger) and were unable to identify it as the cause when installing the gauge at Low Nibthwaite with us, even when using their oscilloscope.

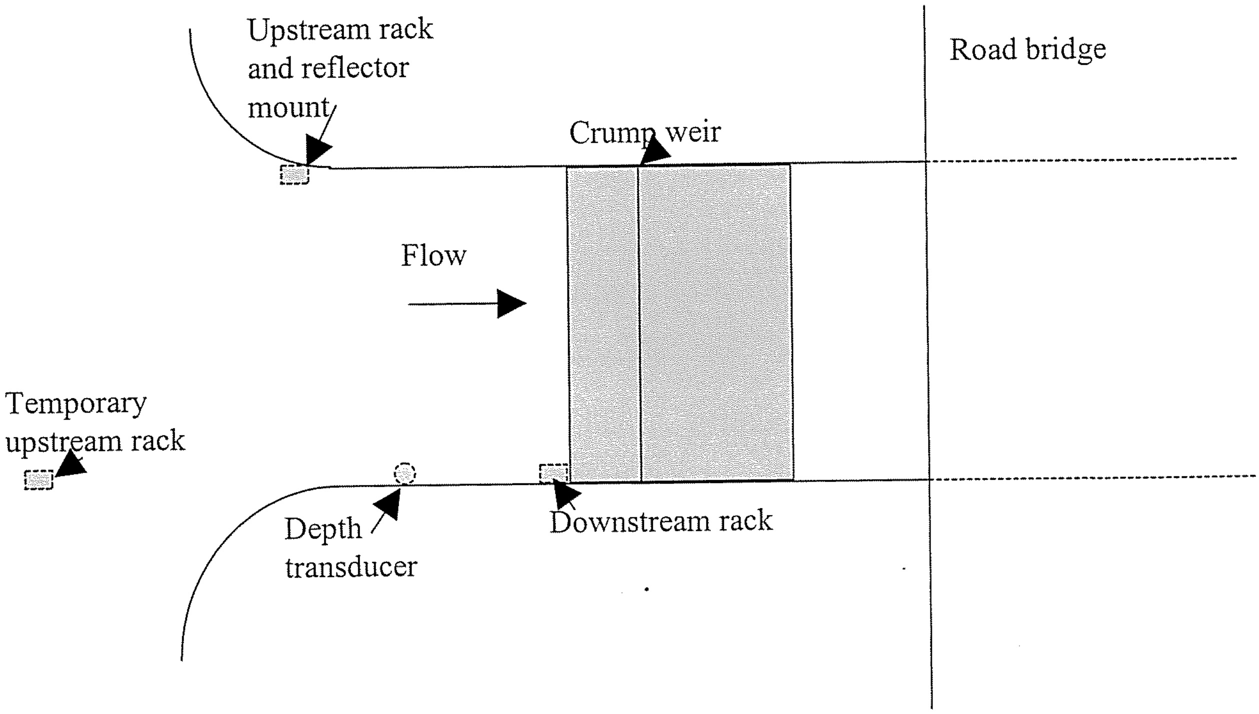


Figure 2.1 Schematic diagram of the gauge installation at Lea Hall gauging station on the Aldford Brook (not to scale).

3 RECORDED FLOWS

One of the potential advantages of using Lea Hall was that it was supposed to experience a wide range of different hydraulic and flow conditions. Unfortunately this potential advantage turned out to be a significant disadvantage - the gauge operated under one of two conditions for the majority of the time it was installed at the site. These two differing conditions were as follows:

1. Very low flows, with typical levels over the weir being less than 100mm. Under these conditions the weir at the site was very insensitive, particularly as it has a slight leak around the grp.
2. More typically, flows were backed up from the confluence with the River Dee. Under these conditions the flows recorded by the Agency were meaningless - whilst the Aldford Brook itself may have had a flow of less than 150 l/s, the Agency rating indicated modular flows of more than ten times this. The situation was so extreme that on two of the fourteen site visits the 1408 gauge indicated that the river was flowing upstream. Recorded flows

by the 1408 ranged from -0.118 cumecs to 0.777 cumecs for a difference in stage of only 45 mm.

It can thus be seen that to undertake any comparison between Agency flows and those calculated by the ultrasonic gauge would be meaningless. Consequently, the gauge was removed from the site on the 1st March 1997, exactly four months and 14 sites visits after it had been installed. This was the shortest period of deployment of a gauge at any of the field sites.

4 GAUGE PERFORMANCE

As section 3 has explained, it was not possible to undertake any comparison of flows at Lea Hall due to the uncertainty in the Agency flows. However, the following results and observations did arise from the Lea Hall studies:

- It was confirmed that the gauge works under very low (and even negative) velocity conditions, caused by downstream backing up.
- It was confirmed that the transducers work in small and confined (<3 m wide) channels.
- It was confirmed that the gauge works from a direct 240v supply.
- It was confirmed that setting the mean bed level to the surveyed level, and the bed correction factor to an initial estimate of 0.65, allowed the gauge to produce more accurate flows than if the bed correction factor was left at the default setting of 0.8.
- With one exception the levels recorded by the gauge were within 4 mm of those recorded by the Agency shaft encoder. The one exception was when the 1408 was recording a level to within 2 mm of that shown on the staff gauge, whilst the stilling well was 30 mm below this. These results confirm that a depth transducer mounted directly in the channel will provide consistent and true data, particularly if one of the velocity paths is continually submerged (in this case, the lowest path was always below the weir crest).
- The only component failure to occur during the project occurred with the gauge that was initially installed at Lea Hall - one of the main cards in the unit had failed, the first time that this had ever happened as far as Peek were aware.

5 OTHER STUDIES UNDERTAKEN AT LEA HALL

Whilst it was not possible to carry out a detailed assessment of the gauges ability to measure flows at Lea Hall, the site did prove to be useful in that it enabled a number of other studies to be carried out. These related to the evaluation of reflector systems, and velocity profiling studies.

5.1 Reflector trials

Work was undertaken at Lea Hall over the weekend of 15-16 February 1997 to try out different reflector systems. The period coincided with relatively high levels at the site caused by the River Dee having backed up the channel. Consequently, although levels were high the velocities were low, typically 0.1 m/s. River levels were falling throughout the study period.

A total of five different reflector systems were tried, listed below:

1. Reflecting the signal off the concrete wall.
2. An angled reflector, as described in ISO 6416: 1992 (E), made from 75mm aluminium angle mounted onto one of the transducer block supports.
3. A small reflector plate, 300 mm by 100 mm, made of 6 mm aluminium. This was mounted both vertically and horizontally, again attached to one of the transducer block supports.
4. A larger reflector plate, measuring 300 mm square, made of 5 mm steel plate and mounted onto one of the transducer block supports.
5. Finally, a steel plate measuring 1200 mm by 300 mm by 5 mm was used. This stood on the channel bed and was clamped via a horizontal brace to the transducer rack.

For all reflector trials the lower of the transducer paths was left in the original configuration at a level of 50 mm below the crest of the crump weir. The reflected path was only used for the higher path, 350 mm above the weir crest. The 'additional' transducer rack that was required on the near bank was temporarily installed immediately upstream of the weir wing walls, as shown in Figure 2.1.

Of the five different reflectors listed above only the last one worked, the 1200 by 300 mm steel plate. Intermittent readings were obtained from No 4, the 300 by 300 mm plate, but the count return was very low and did not exceed 8 out of a possible 255. It was thus decided to undertake a more extensive trial with the large reflector plate. During this trial the gauge was operated in the following sequence:

- Both upper and lower paths at original configuration;
- Upper path only, with reflector *in situ*;
- Lower path only;
- Upper path only, with reflector *in situ;*
- Return to original configuration.

Typically, up to ten sets of readings were taken at five minute intervals for each configuration. The results from these trials are shown in Table 5.1, and plotted in Figure 5.1.

Table 5.1 Data collected from the reflector trials undertaken at Lea Hall on the 16th February 1997. The data are presented in order of collection, ie the first row of data were the first to be collected. Levels are in metres, flows in cumecs, and velocities in metres per second.

Stage	Gauge flow	Low path velocity	Low path count (max 255)	High path velocity	High path count (max 255)
Original path configuration					
0.595	0.265	0.090	255	0.108	255
0.595	0.264	0.098	255	0.100	255
0.595	0.264	0.093	255	0.105	255
0.594	0.263	0.096	255	0.097	255
0.594	0.263	0.098	255	0.100	255
0.593	0.264	0.096	255	0.104	255
0.593	0.264	0.098	255	0.103	255
0.592	0.263	0.092	255	0.099	255
0.592	0.264	0.100	255	0.102	255
0.591	0.264	0.097	255	0.103	255
Mean	0.264	0.096	255	0.102	255
Upper path only, reflected velocity path					
0.561	0.246			0.094	210
0.561	0.245			0.094	212
0.561	0.248			0.095	212
0.56	0.244			0.093	210
0.56	0.244			0.093	207
0.559	0.247			0.094	255
0.559	0.243			0.093	210
0.559	0.244			0.093	210
0.559	0.242			0.093	170
0.559	0.233			0.089	211
Mean	0.244			0.093	211

Table 5.1 (continued) Data collected from the reflector trials undertaken at Lea Hall on the 16th February 1997. The data are presented in order of collection, ie the first row of data were the first to be collected. Levels are in metres, flows in cumecs, and velocities in metres per second.

Stage	Gauge flow	Low path velocity	Low path count (max 255)	High path velocity	High path count (max 255)
Lower path only, original configuration					
0.561	0.127	0.098	213		
0.561	0.126	0.097	210		
0.561	0.128	0.099	212		
0.56	0.132	0.102	212		
0.559	0.125	0.096	209		
0.559	0.129	0.100	175		
0.559	0.126	0.097	169		
0.559	0.125	0.096	255		
0.559	0.128	0.099	211		
0.558	0.124	0.096	189		
Mean	0.127	0.098	206		
Upper path only, reflected velocity path					
0.546	0.207			0.081	91
0.545	0.234			0.091	79
0.543	0.097			0.038	194
0.543	0.098			0.038	211
0.543	0.088			0.034	201
0.542	0.095			0.037	159
Mean	0.164			0.064	187
Original path configuration					
0.54	0.259	0.098		0.107	210
0.539	0.271	0.104		0.110	209
0.539	0.269	0.100		0.114	210
0.538	0.269	0.105		0.107	211
0.538	0.256	0.098		0.105	208
0.542	0.254	0.094		0.107	212
0.538	0.258	0.101		0.104	211
0.537	0.25	0.094		0.104	209
0.537	0.253	0.094		0.108	212
0.537	0.258	0.099		0.106	201
Mean	0.26	0.099		0.107	209

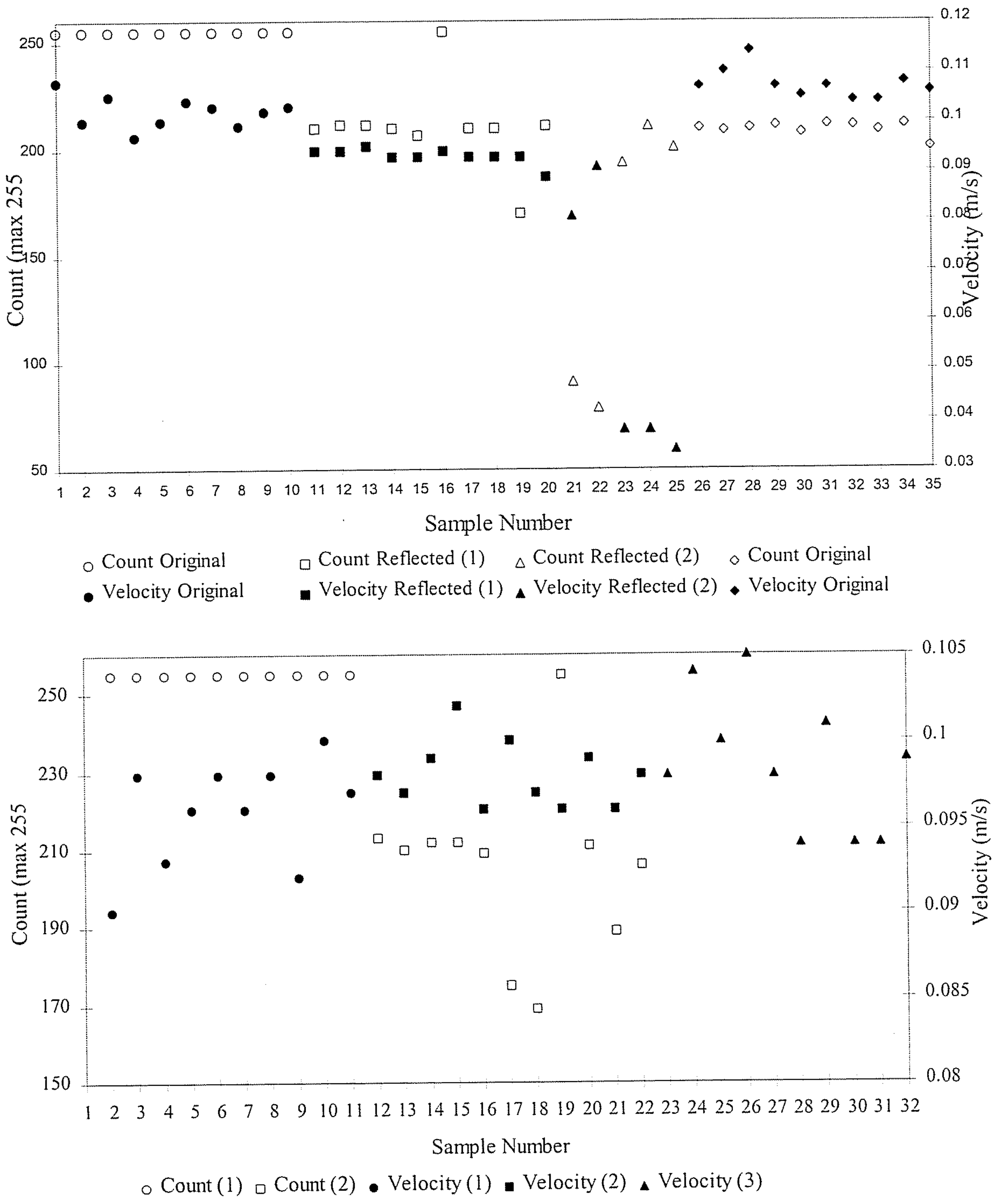


Figure 5.1 Velocity and count data for the high and low transducer paths collected during the reflector trials at Lea Hall, and as presented in Table 5.1. (1), (2), (3) etc indicates the sequence in which the readings were taken. The reflector was only used to obtain velocities along the high path, as plotted in the upper of the two graphs. All count values are out of a maximum of 255, and velocities are in metres per second.

A number of points can be made about the data contained in both Table 5.1 and Figure 5.1. These are summarised below:

- Both transducer paths recorded maximum counts **before** studies commenced in the channel. However, once work had started after the first ten sets of readings, the count of successful pulses reduced for both paths. This was due to sediment on the channel bed being disturbed whilst work was underway.
- Throughout the study period the velocities recorded along the lower of the two transducer paths appear to have increased as river levels fell. Consequently, river flows did not significantly alter during the period, even though levels in the River Dee may have.
- Similarly, the data from 'original' velocity configuration for the upper transducer path were also higher at the end of the study period than at the beginning.
- The first set of 'reflected' velocity data (Velocity Reflected (1)) plotted in Figure 5.1 are slightly lower than the original set of velocity data. This is physically reasonable if it is remembered that these data were collected from further upstream of the weir, where the acceleration effect as the water approaches the weir crest will have been less.

These observations appear to indicate that the reflector trials at Lea Hall were successful in that they not only confirmed that the reflector was able to provide consistent and reasonable data, but that subtle differences in the flow characteristics could also be detected. However, the data relating to the second set of reflected data are much less reassuring. In addition to recording very low count values, often less than 100, this set of data also recorded much lower velocities. It is not known why this is the case, particularly as the very low velocities are actually associated with the highest 'count' values. What it does indicate is that the reflector system appears to be less dependable than the straightforward configuration. When this is combined with the fact that it took considerably longer to align the reflector than the velocity paths, it would suggest that the reflector system should only be used where absolutely necessary.

5.2 Velocity profile studies

One potential approach that was identified at the start of the Project was to alter the level of the transducer paths **during** an event whilst staff were on site. In addition to allowing accumulated debris to be removed from the transducers, this also enabled detailed velocity profile data to be collected from Lea Hall during a number of events. Given the deep and narrow channel, and the fact that the water velocities can be very low when the river was backed up, it may be desirable to assess the nature of the velocity profile under these conditions. This data may then be used in trying to identify an alternative solution to the monitoring of flows at the site.

Detailed velocity profile data were collected between 0810 and 0900 on 1st March 1997 from nine different transducer path levels. Five one-minute readings were taken at each of the nine levels, and the mean path velocities are plotted in Figure 5.2 below. It can be seen that, even under such low flow conditions, the gauge is sensitive enough to provide consistent data that enable the velocity profile to be derived. Low velocity readings were obtained near to the channel floor, and increase with depth up to a level equivalent to the weir crest. Peak velocities were found in the 350 mm of water immediately above the weir crest, before decreasing towards the water surface at 0.625 metres. It is thus concluded that the gauge is suitable for use under these conditions if required.

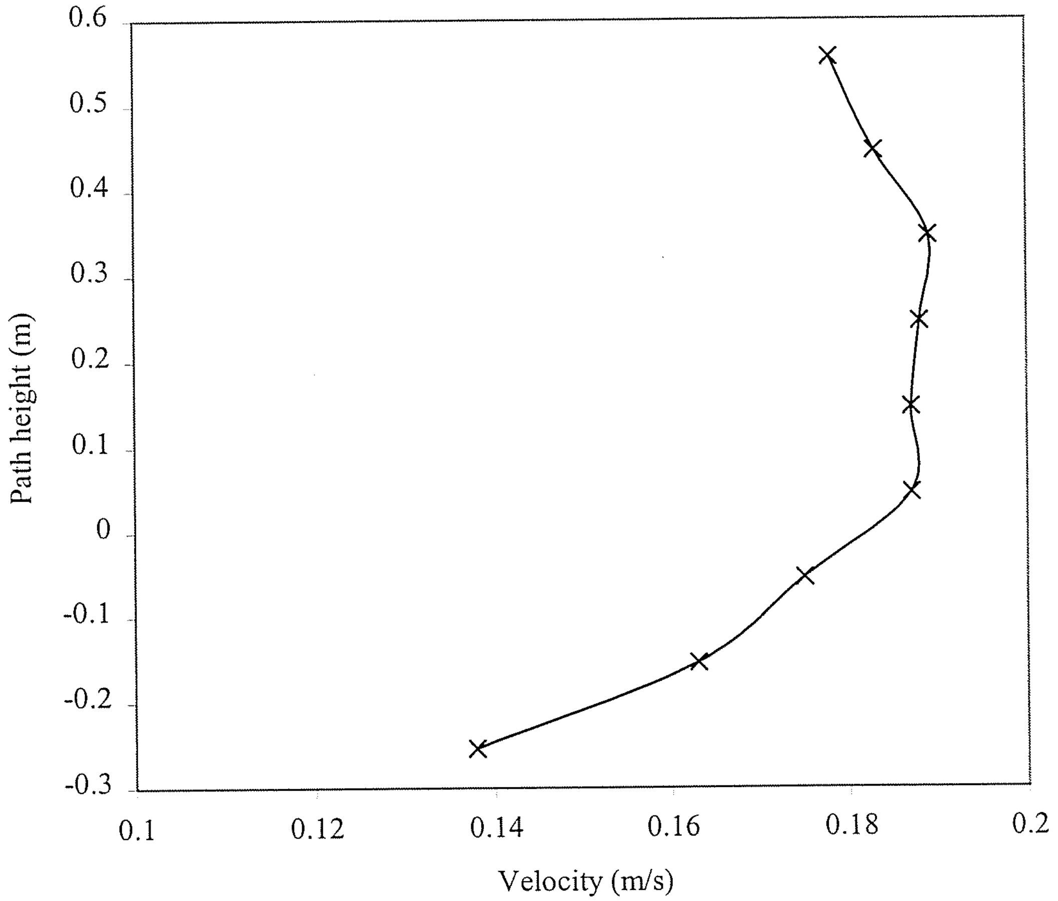


Figure 5.2 Velocity profile data collected at Lea Hall on 1st March 1997 when the channel had backed up. Individual data points are the mean of five one-minute readings at each level. The mean river level during the study period was 0.625 metres

6 SUMMARY

Although the studies at Lea Hall may not have been as prolonged as those at the other field sites, a significant amount of useful material was obtained. This was aided by the availability of what was effectively an 'outside laboratory' due to the compact size of the site, which enabled many different approaches and alternative pieces of equipment to be evaluated in a relatively short length of time.

Whilst the Lea Hall studies may have confirmed many of the findings from the other field sites, they also provided most useful results of their own. These relate to the reflector studies and the velocity profile measurements. The former showed that whilst it may be possible to operate the gauge using a reflector system, this may be accompanied by a slight decrease in gauge performance. In contrast to this, the velocity profile studies demonstrated that the twin path ultrasonic gauge offers a viable alternative to the more conventional array of current meters and, if a suitable mounting system is used, may result in a significant saving in time.

12 LOW NIBTHWAITE SITE REPORT

1 INTRODUCTION

Low Nibthwaite gauging station is used by the North West Region of the Environment Agency to monitor flows on the River Crake, which drains Coniston Water in the south west Lake District. The station is approximately two km downstream of Consiton Water, which is the dominant hydrological control and tends to result in a subdued hydrograph response to rainfall events.

The site was the second one to be selected for the project and was to be used in tandem with Greenholme; the reasons for this choice include:

1. The station had an LF1, MF1, HF1 classification, indicating that good quality flow data are recorded by the Agency.
2. The station has an artificial control structure, stable rating and is weed free.
3. The station has a cableway u/s of the control that could be used to convey the transducer cables.
4. The channel reach that was to be used for the study had straight, vertical stone walls. This would enable four sets of racks to be used at the site in a cross path configuration.
5. The site offered good security and access.
6. It was possible to travel to the site within one and a half hours of leaving base, thus maximising the chances of being on site during high flow conditions.
7. This was further enhanced by the fact that whilst Greenholme is an open channel river site which is relatively quick to respond due to the steep tributaries, Low Nibthwaite should be much slower to respond as it is below Coniston Water which will tend to attenuate any high flow events. Thus, when/if such events occur, we could travel first to Greenholme (< 1 hour travel time) before moving on to Low Nibthwaite. This was an especially important factor for the first winter season when we intended to concentrate on evaluating the performance and limitations of the equipment.
8. The channel width at Low Nibthwaite falls on the border between the 1MHz and 500 KHz transducer requirements.
9. High flows are contained within bank.
10. The site potentially offered a wide range in stage, ensuring that different transducer configurations could be evaluated.

2 GAUGE INSTALLATION

The installation at Low Nibthwaite was carried out on 10 January 1996 by a technician from both peek and SWS. Work again started on site at 0900, with the Peek technician leaving at 1600. The SWS technician remained on site until 1800 to tidy up the cables.

Whilst the Greenholme site used the gauge with only four transducers operating in-line as two paths, it was decided as part of the Scoping Study to operate eight transducers at Low Nibthwaite with four paths in a cross-path configuration at two levels. It was hoped that by doing this it would be possible to evaluate the benefits (if any) of cross-path configuration, as-well as using both the 1 MHz and 500 kHz transducers. Figure 2.1 shows the layout of the gauge components at the site.

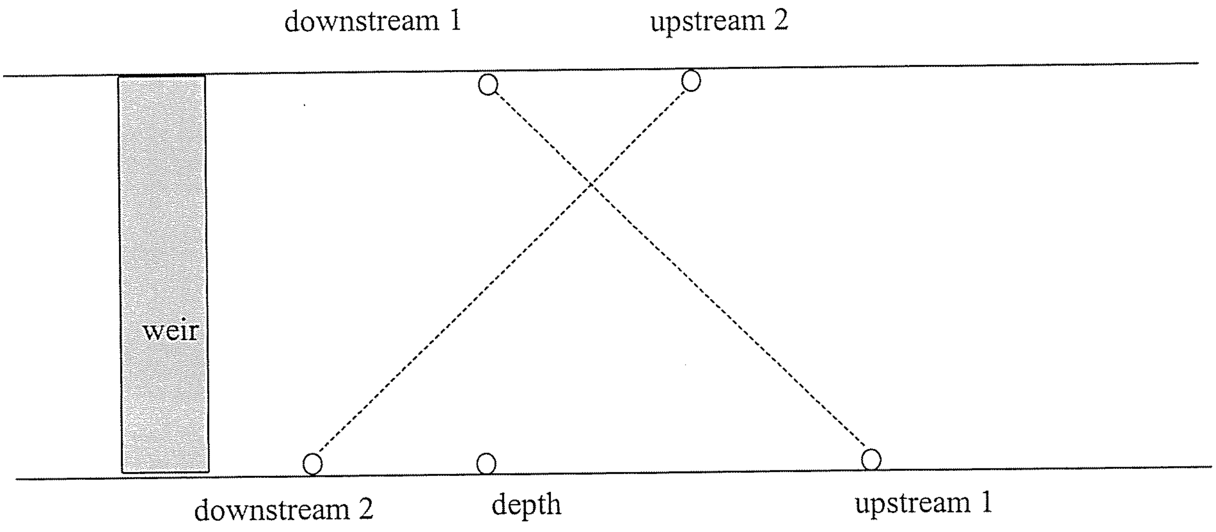


Figure 2.1 Schematic layout of the gauge components at Low Nibthwaite. Transducer velocity path 1 used the 500 KHz transducers, whilst velocity path 2 used the 1 MHz transducers.

Because of the additional set of transducers it could not be guaranteed that all paths would be commissioned during the single day. Efforts were thus initially concentrated on the 500 kHz transducers, which were successfully commissioned by 1200. The additional set of transducers were commissioned by 1430, with all 'technical' matters being completed by 1600. However, unlike Greenholme, it was not possible to merely line up the transducers by sight and the oscilloscope was needed to fully align the paths. Considerable difficulty was experienced in setting up the depth transducer due to electrical interference and Peek recommended that it was reinstalled at a later date, either as a tube gauge in the river or in the station stilling well.

The breakdown of time spent at Low Nibthwaite is as follows:

Site survey	6 man hours
Site preparation	16 man hours
Installation/commissioning	16 man hours
TOTAL	38 man hours

Approximately twenty or so additional hours were spent trying to sort out the problems of the depth transducer at the site. It was later found (at Lea Hall) that the problems were not due to the gauge itself, but arose due to electrical interference from the battery charger that had been connected in-line to the power supply.

It can thus be seen that whilst almost twice the amount of equipment was installed at Low Nibthwaite than at Greenholme (where the installation time was 32 hours) the time taken does not reflect this. Whilst this is partly due to the size of channel at both sites (the Irthing is almost three times as wide as the Crake) we feel it also suggests that time can be reduced the more familiar one is with the equipment.

3 RECORDED FLOWS

The very dry winter of 1995/96, combined with the damping effect of Coniston Water, resulted in very minor fluctuations in flow at the site. Five 'events' were recorded at the site, enabling the gauge to be operated in a number of configurations, as shown in Table 3.1.

Table 3.1 Details of timing and path configuration for the five events recorded at Low Nibthwaite.

Period	Start of event	End of event	Lower path level (m)	Upper path level (m)	Transducers used
1	0900 on 11/02/1996	1200 on 15/02/1996	0.104	0.304	500 kHz
2	1500 on 15/02/1996	1200 on 25/02/1996	0.104	0.304	1 MHz
3	1500 on 25/02/1996	1200 on 08/03/1996	0.104	0.404	500 kHz
4	0900 on 15/04/1996	0900 on 09/05/1996	0.104	0.504	500 kHz
5	0900 on 22/05/1996	0900 on 01/06/1996	0.104	0.504	500 kHz

4 GAUGE PERFORMANCE - RELIABILITY

Date returns from Low Nibthwaite were rather less rewarding than those from Greenholme for a variety of reasons. Firstly, as previously mentioned, the gauge was at best erratic in measuring depth and considerable time was spent trying to resolve this. By reducing the gain on the instrument circuit board and increasing the voltage the signal was been improved, although it was later found that the problems were not due to the gauge itself. Reassuringly, the Peek technician was unable to resolve the problem with an oscilloscope when on site.

The second problem that occurred at Low Nibthwaite was not due to the gauge itself but was a result of very heavy snowfalls during January 1996. These caused extensive damage to the fir tree which overhangs the gauging station and river section, and the broken boughs resulted in the transducer paths being blocked. The NRA kindly removed these at our request but, unfortunately, in doing so the alignment of the transducers was altered. We subsequently managed to realign these without using a 'scope, and then managed to get higher counts than before the disturbance!

Whilst it was expected that events would be attenuated, the reality is that they were barely perceptible and took place over a matter of weeks rather than days. The transducer mounting system allowed us to take advantage of this, facilitating the rapid alteration of path levels and trying different configurations when on site.

On a more positive note, the gauge continued to collect velocity data from a total of five different paths at three different levels. It was possible to change from one set of transducers to another within a matter of minutes which gave a wide range of options for using the gauge in different configurations, and increases the flexibility of the equipment.

5 GAUGE PERFROMANCE - FLOW MEASUREMENT

It was agreed at the Project Board meeting which followed the 1995/96 winter that the lack of significant events at Low Nibthwaite meant that there was little point in undertaking extensive analysis of the recorded data. Instead, the most significant event recorded at the site (event 1 in Table 3.1) would be used to demonstrate that the gauge did perform as expected and that, when coupled with suitable level data, is able to calculate flows from the recorded path velocities.

As the equipment was installed at Low Nibthwaite on the day after the Greenholme gauge was installed the mean bed level and bed correction factors were also set to the default parameters.

The analysis described in the Greenholme Site Report and Chapter 4 of the Technical Report indicated that the gauge performance could be improved by optimising the bed correction factor. This was done for the Low Nibthwaite event, and Figure 5.1 shows the Agency flow data between 1200 on the 11th and 1200 on the 15th February 1996, together with those calculated from the default gauge data, and the % difference data between the Agency and gauge flows. It can be seen that the 'Gauge flow' series is considerably more 'spiky' than that produced from the Agency data; this is because the depth transducer was providing erratic data due to problems with the power supply, as described earlier. The 'Adjusted flow' data series was thus derived from the Agency stilling well level data and the data collected from the two velocity paths, with the bed correction factor being optimised on the basis of the first four flow values.

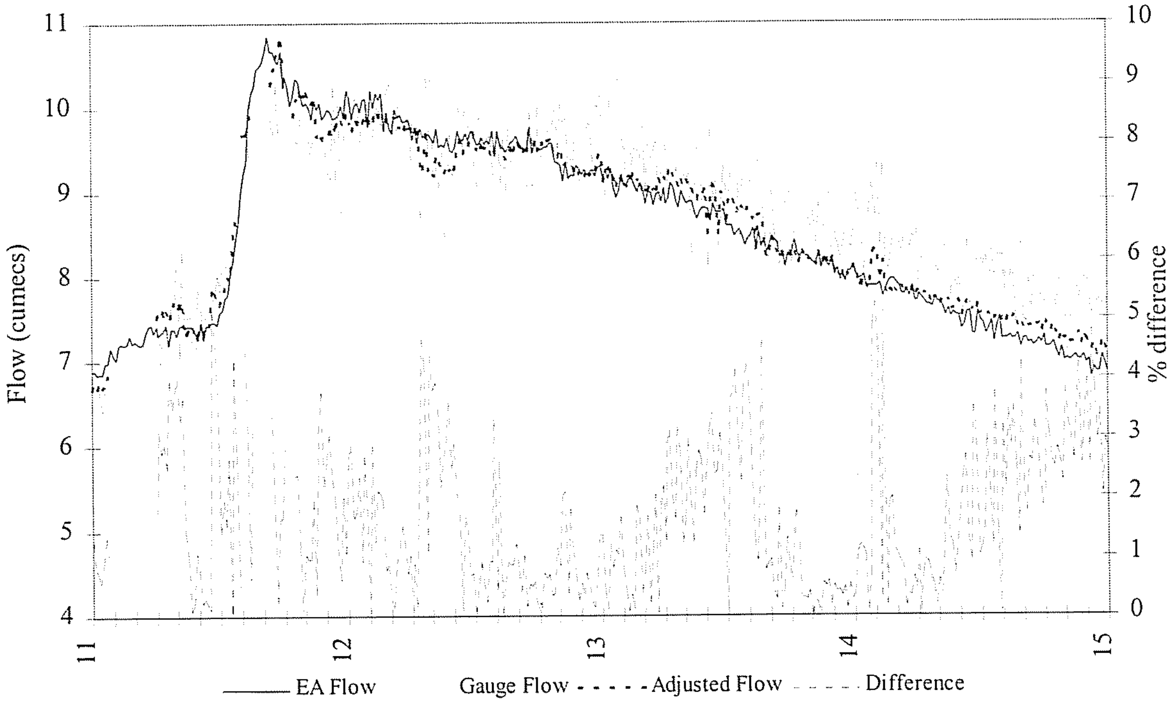


Figure 5.1 Agency, gauge and adjusted gauge flows at Low Nibthwaite between 1200 on the 11th and 1200 on the 15th February 1996. The transducers paths were deployed at 0.1 and 0.3 metres above stage datum, and the maximum stage during the event was 0.726 metres. Tick marks are at two hour intervals.

It can be seen from Figure 5.1 that the gauged flows at Low Nibthwaite agree closely with those derived from the Agency stage discharge calibration, The mean difference between the Agency and gauge flows (corrected) is only 1.7%, with very few 15-minute values exceeding the 4% threshold. Similar results were found for the other five lesser events that were recorded at the site.

6 SUMMARY

Whilst the flow conditions that were encountered at Low Nibthwaite did not enable as thorough an evaluation of the equipment to be undertaken as had been anticipated, a number of useful results were obtained.

The strongest outcome to arise from the site were the problems associated with using battery chargers to keep a 12-volt supply on trickle charge, and the electrical interference that this causes. As the studies at Lea Hall demonstrated, had the gauge been operated directly from the mains supply these problems would have disappeared.

In addition to this negative result the following findings also emerged from the Low Nibthwaite studies:

- Confirmation that both 1MHz and 500 kHz transducers were able to work in a channel of approximately 10 metres width.
- Confirmation that the mounting racks enabled the transducer levels to be altered during high flows.
- When suitable level data are available the gauge was able to accurately monitor flows.
- The results of the analysis undertaken on the Greenholme data series were confirmed, namely that setting the bed correction factor on the basis of the first four recorded flow values results in the differences between the gauge and Agency flows being significantly reduced to a mean value of only 1.7% over the highest event recorded at the site.
- Finally, the use of different transducers in a crossed path configuration in a straight and uniform channel confirmed that, where site conditions are suitable, there was no significant difference in the velocities recorded by the two paths.

APPENDIX A
Gauge settings used at Low Nibthwaite

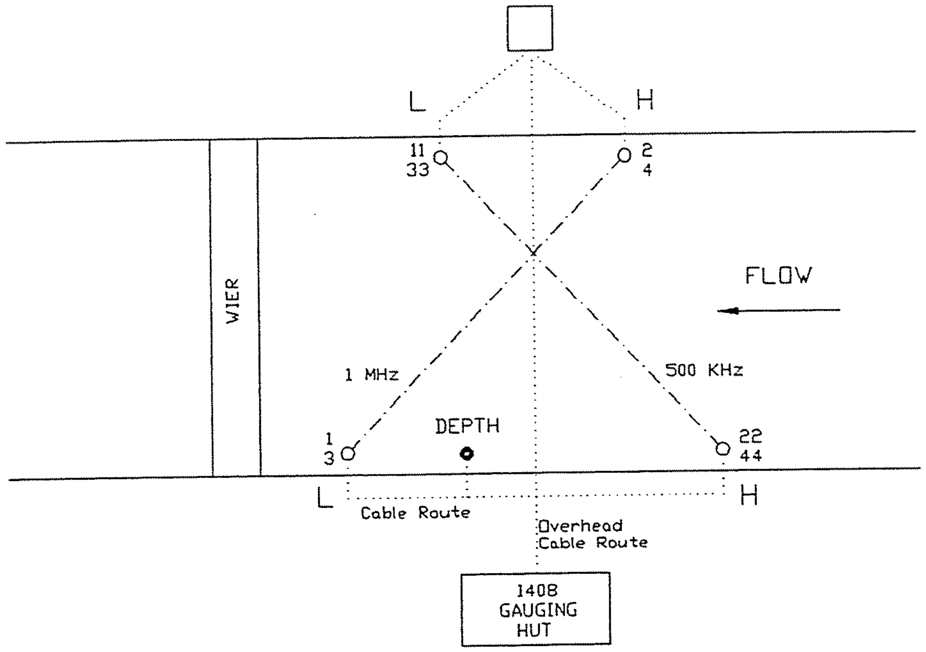
CONTENTS

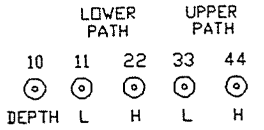
Page

1. SITE DATA

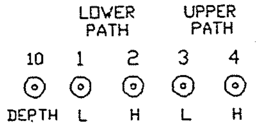
Number of velocity paths	2
Number of ultrasonic depth paths	1
Number of auxiliary depth gauges	0
Auxiliary depth gauge type	-
Transducer details	Incastec 500 khz, 50mm **(Incastec 1 MHz)**
Power supply	2off 12v d.c. Dryfit Batteries (Connected in parallel)
Output Cards	None

1.1 Path Configuration





1408 BNC CONNECTIONS
FOR 500 KHz TRANSDUCERS



1408 BNC CONNECTIONS
FOR 1 MHz TRANSDUCERS

2. PROGRAMMED DATA

2.1 Operational Data

GENERAL DATA **(1Mhz Values in Bold)**

Path Configuration : In Line
Height Reference : A.O.D.
AOD of Mean Bed Level : -0.470 Metres
AOD of Aux Depth Zero : N/A
Flow Units : Cumecs

DEPTH DATA

Transducer Height : -0.028 Metres
Calibration Coefficient : 1
Maximum Height : 2.000 Metres

VELOCITY DATA	Path #L	Path #H	
Transducer Height	: 0.104	0.304	Metres
Path Length	: 11.805 **(11.240)**	11.805 **(11.240)**	Metres
Calibration Coefficient	: 1	1	
Angle to Flow	: 45 **(47.6)**	45 **(47.6)**	Degrees

2.2 Preset Data

GENERAL DATA

Aux. Depths Status : 0=16 1=16 2=16 3=16
No. of Vel. Paths : 2
Ring Test Time (μS) : 256
Vel of Sound : 1426.35 (Calculated by system)
Minimum Cover (M) : 0.130 **(0.090)**

DEPTH DATA

Address : 129
Identifier : 127
Depth Identifier : 255
Existence : 0 (Changed by System)
Minimum Depth (ms) : 0.290

VELOCITY DATA		Path #L	Path #H
Address	:	130	131
Delay L (μS)	:	4	4
Delay H (μS)	:	4	4
Maximum Time Diff	:	2	2
Certification	:	0	0

2.3 Time & Output Data

Site Reference Number : 1234

Analogue Output Values

Maximum Flow : 0
Maximum Depth : 0
Minimum Flow : 0
Minimum Depth : 0

2.4 Velocity Factor Tables

When installed all 4 tables were set up with the level multipliers set to 1, and the bottom section multiplier set to 0.8. The tables will be configured when sufficient velocity profile data has been obtained for the site.

3. TRANSDUCER BOARD - Configuration

Velocity Transducer EHT= 200 Volts	Link 1 Open Link 2 Open Link 3 Closed Link 4 Off Link 5 Off
Depth Transducer Voltage +15 volts	Link 9 + 15v
Amplifier Gain = 40 dB	Switch 1/1 On (off) Switch 1/2 On (on) Switch 1/3 Off Switch 1/4 Off Switch 2/1 Off Switch 2/2 Off Switch 2/3 Off Switch 2/4 Off
-1 Volt Condition True	Link 6 Removed
Amplifier O/P Polarity -ve 1st	Link 7 Top position

4. DATA OUTPUTS

4.1 RS232 Output

This uses the same interface as the GCP communication, to provide log information suitable for a Psion organiser.

Header Record : - sent on power up and at 9 o'clock every day
(to check the correct time stamp)

- format
<H> - ASCII H for header identifier
hh - time, 2 digits of hour
mm - time, 2 digits of minutes
<,> - comma separator
dd - date, 2 digits for day of month
mm - date, 2 digits for month
<cr> - ASCII carriage return
<lf> - ASCII line feed

Data Record : - sent every 15 minutes (all 1 minute values)

- format
<D> - ASCII D for data identifier
hh - time, 2 digits of hour
mm - time, 2 digits of mins
<,> - comma separator
ffffff - flow, 6 digits (decimal point implied)
<,> - comma separator
dddd - depth, 4 digits (last 4 digits of display)
<,> - comma separator
vvvv - velocity L, 4 digits (last 4 digits of display)
<,> - comma separator
vvvv - velocity H, 4 digits (last 4 digits of display)
<cr> - ASCII carriage return
<lf> - ASCII line feed

Example

H1035,0712 - power up header - 10:35 hrs, date 07/12

D1045,001234,5678,0123,0234 - data - time 10:45 hrs, flow 1.234 cumecs,
depth 5.678m, vel L 0.123m/s,
vel H 0.234m/s

D1100,-01236,9863,-102,-103 - data - time 11:00 hrs, flow -1.236 cumecs,
depth 9.863m, vel L -0.102m/s,
vel H -0.103m/s

H0900,0812 - 9 o'clock header - 09:00 hrs, date 08/12

D0900 .... - data record for 0900 hrs
(same format as above)

The 1408 assumes GCP is connected unless 'pin 5' is high when it recognises that the Psion is connected. The Psion automatically sets this pin high. The cable connections between the 1408 and the Psion are:

1408		Psion
2	-------------------	2
5	-------------------	5
7	-------------------	7

13 MIDDLETON IN TEESDALE SITE REPORT

1 INTRODUCTION

Middleton in Teesdale gauging station is a velocity-area station located in the upper part of the River Tees catchment. The catchment is predominantly of an upland nature, draining the northern Pennines. The river section adjacent to the station is steep, and has a gravel and rock bed. The gauged area is 242 km^2.

The station control is a non-standard flat V weir, which has a limited modular range. The site was chosen as a suitable study site for a number of reasons. These include:

- The upper Tees catchment is known to be very flashy, with river levels rising quickly following rainfall events. Even through the very dry 1995/96 winter, the station had experienced a number of high flow events.
- High flow events at the station cause a significant (i.e. > 1 metre) rise in water levels, ensuring that the equipment could be tested at different levels.
- The station has been gauged throughout the majority of its range by Agency/NRA personnel, ensuring that there was good confidence in the 'true' flow data.

The river channel was both wide and deep, and the velocities were known to be high. This would ensure that the equipment would be tested under the most challenging of conditions encountered during the Project.

2 GAUGE INSTALLATION

The gauge was installed in March 1997, and removed in December 1998. The configuration of the installation is shown in Figure 2.1. As with the majority of the field sites the cables from the far bank set of transducers were routed across the river on a catenary cable, running from the top of the far tower of the gauging station cableway to the wall of the station itself. The depth transducer was installed in the stilling well to ensure that there would be sufficient depth of water for it to function all year round.

Of all the sites used for the Project the installation at Middleton was the most difficult, and required two personnel to work on site over two days to complete. A total of 26 man hours were spent on the survey, installation and commissioning. Whilst the weather was a contributory factor in this (it was so cold that the river water being used to mix the concrete kept freezing), the actual site conditions also caused considerable problems for a 'temporary' installation. Factors that has to be taken into account include:

- The wide range in river levels - up to four metres.
- The high velocities during flood events.
- The river bed - a mixture of boulders, gravel and bedrock.

- The proximity of the site to public footpaths on both banks.
- The geometry of the channel section - wide, with a curved river bed.

This final factor, the channel geometry, required careful consideration when deciding where to install the transducer racks. Due to the curved nature of the river bed it was necessary to compromise between maximising the path length, i.e. setting the racks as far apart as possible, and minimising the depth between the lowest path and the river bed, i.e. bringing the racks in towards the centre of the channel. The latter option also brought the potential penalty that the river velocities would be higher towards the centre of the channel, and the probability of the rack being hit by river debris would be increased. It was finally decided to install the racks approximately two metres in from either bank, where it would be possible to set the lowest transducer path approximately 0.65 metres above the mean river bed level.

The racks were amongst the tallest used for the Project at 2.5 metres tall, enabling the highest potential velocity path to be set at 2.7 metres above stage datum. The gauge performance at the site meant that, in the end, the top 1.5 metres of the racks were not used. The racks themselves were mounted onto a steel stanchion which was set into concrete, cast underwater. Both stanchions were then braced on the downstream and river bank sides, enabling a firm and vertical frame for the racks to be created. The stanchions survived two winters of high flow events at the site, and even presented problems when the time came to remove them and the braces.

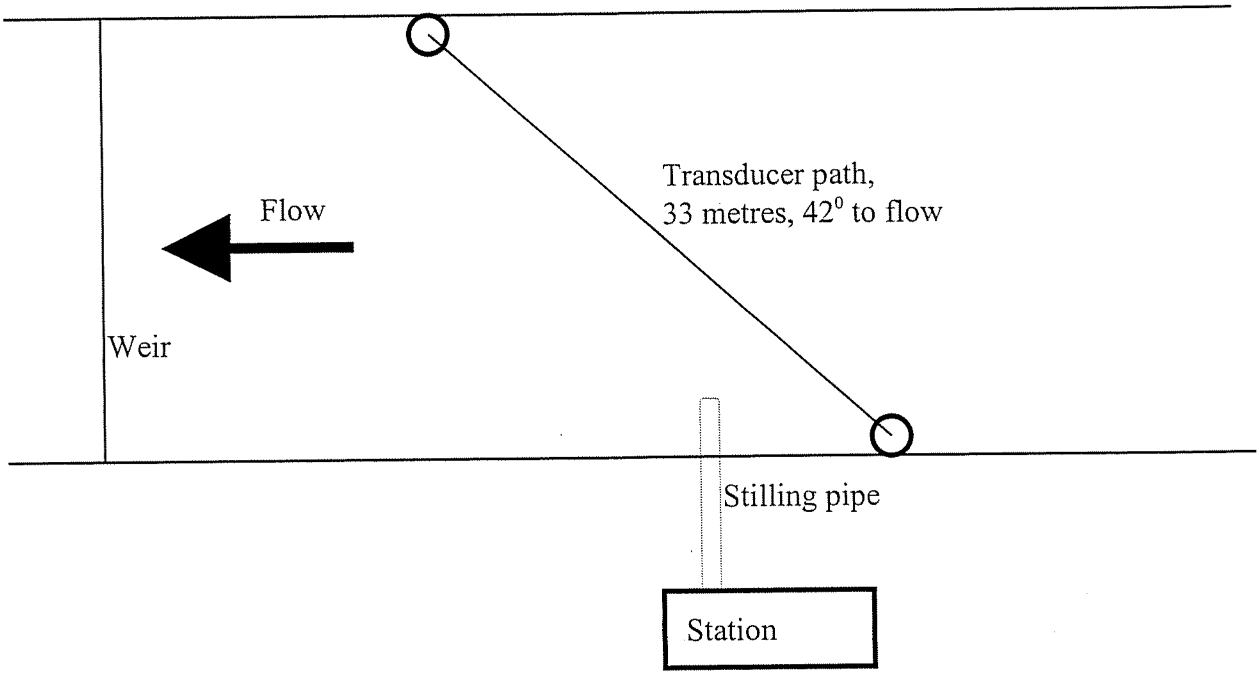


Figure 2.1 Schematic plan of the gauge installation at Middleton in Teesdale. The transducer racks were set in approximately two metres from either bank.

For the majority of the study period the gauge operated with two paths of 500 kHz transducers. For reasons that will be explained later in this report, it was decided to evaluate some larger 250 kHz transducers at the site, and these were installed on the lower path on 11th August 1998.

3 SUMMARY OF EVENTS RECORDED AT THE SITE

Unlike the other sites used for the Project, Middleton experienced many high flow events during the period that the equipment was installed. However, and most disappointingly, the gauge struggled to work consistently at the site, and was generally unable to record velocities once the river level rose above a stage of between 1.0 and 1.2 metres. Limited velocity data were collected from higher levels; the usefulness of these will be discussed later in the report.

The transducers were operated at a total of eight different levels during the study period. The upper path did not operate during any event. When this factor is combined with the fact that the 250 kHz transducer path also failed to work, the result is that velocity data were only collected for three different levels. These were 0.4, 0.5 and 0.7 metres above stage datum. A summary of the events which have been used for the analysis presented in this report is contained in Table 3.1. Additional events were used for assessment of the gauge performance at measuring water level within the stilling well.

Table 3.1 Summary details of the principal events from which velocity data were collected at the three different levels. All levels are relative to stage datum (metres).

Level of velocity path	Minimum stage	Maximum stage	Start date of event
0.4 metres	0.471	1.275	19/11/1997
0.5 metres	0.582	1.374	21/01/1998
0.7 metres	0.689	1.329	22/04/1998

4 LEVEL MEASUREMENT

The wide range in levels at Middleton theoretically enables a thorough assessment of the gauge performance at measuring river levels to be undertaken. One of the largest events that occurred during the study period was in early January 1998; Figure 4.1 below shows a time series plot of the water level recorded by both the Agency instrumentation and the ultrasonic gauge during this event.

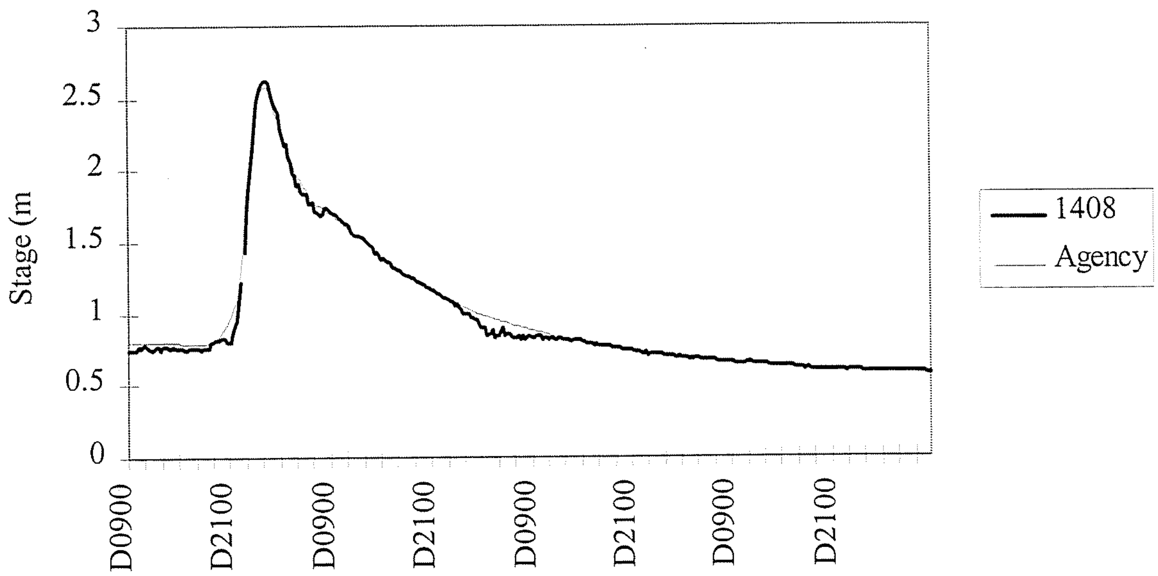


Figure 4.1 Stilling well water levels recorded by both the Agency instrumentation and the ultrasonic gauge between 0900 on the 8th and 0900 on the 12th January 1999. The tick marks on the time axis represent a two hour period.

A number of observations can be made from Figure 4.1:

- In general the instruments correlate well; particularly on the rising limb of the hydrograph.
- Initially, the ultrasonic gauge provided a lower measurement of water level than the shaft encoder used by the Agency. This discrepancy appears to disappear once water levels start to rise, although the two instruments show a different initial response.
- During the (very) steep rising limb of the event the levels recorded by both instruments are effectively the same; the only differences may be due to timing differences between the instruments rather than actual differences in measurement. This is particularly impressive given the rate of rise - almost 1.8 metres in less than three hours. (Note that the 'missing' gauge data represents a single data point; this was because SWS were on site during the event, and had taken the gauge 'off-line' to try and get the velocity paths working.)
- The peak levels recorded during the event are very similar for both instruments, differing by less than 30 mm (1.7%).
- The levels recorded during the recession limb appear to be virtually identical for the majority of the event. However, there are two significant exceptions to this, both of which show the ultrasonic gauge recording a lower level than the shaft encoder. Whilst there are a number of possible explanations for this, they cannot be confirmed without reference to a third set of readings.

Other events were also analysed to assess the extent to which the ultrasonic gauge level data agreed with that of the Agency shaft encoder, and similar results were found. Unlike some of the other sites used for the Project there was no consistent relationship between the gauge's ability to measure depth and whether or not the velocity path(s) were working. Instead, the relationship appeared to reflect a tendency for the gauge to record lower values than the shaft encoder at low river levels, with the two approaching equal values as the river rose. Figure 4.2 overleaf shows a plot of the ultrasonic recorded level plotted against the level recorded by the Agency shaft encoder during the November 1997 event, and this relationship can be clearly seen.

Spot checks during site visits confirmed that neither instrument was consistently correct, with the staff reading in the river often varying from that shown by either instrument. As we cannot be sure whether the shaft encoder or ultrasonic gauge provided the most correct data, and it is suspected that the 'true value' may well vary from event to event, it is necessary to standardise on one set of level data for the analysis of flow data. It was therefore decided to use the Agency levels for all analysis as this would ensure that a consistent comparison could be carried out between the derived flows.

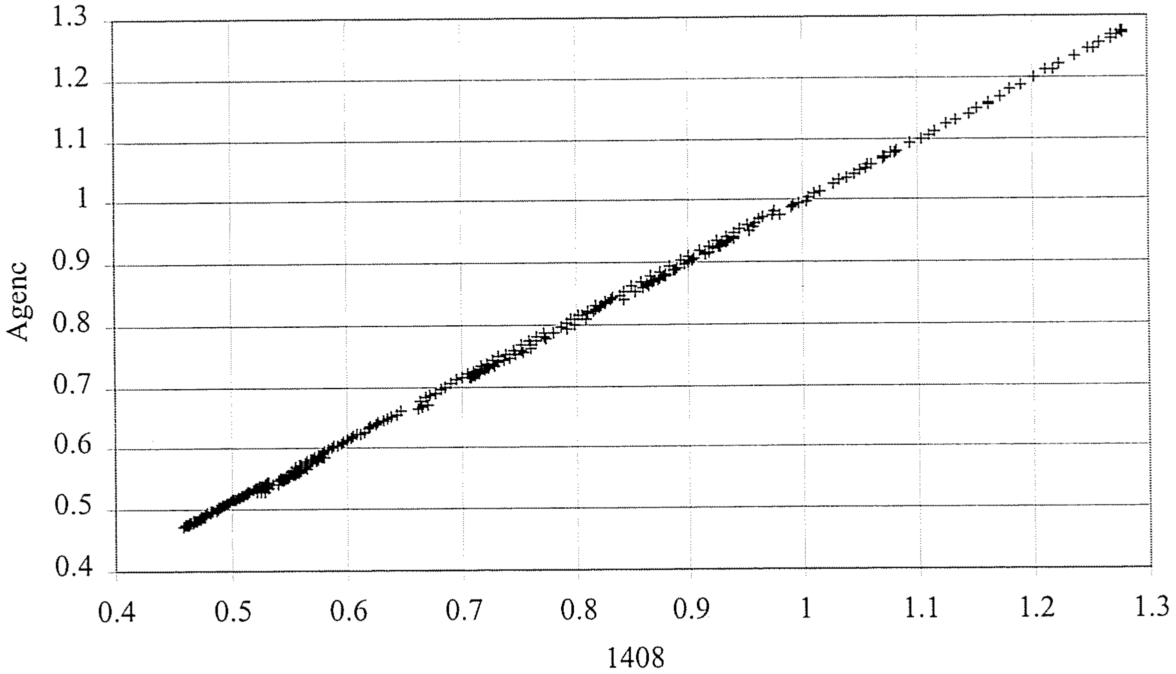


Figure 4.2 Water levels recorded by the ultrasonic gauge plotted against those recorded by the Agency shaft encoder for the November 1997 event. Note that at low levels the ultrasonic gauge tends to record lower values than the encoder, whilst the data appear to match better at higher levels.

5 FLOW MEASUREMENT

The gauge repeatedly failed to measure velocities under high flow conditions throughout the entire study period. Many different gauge settings were used, with different voltages, gain and board settings tried in an attempt to improve the data. The site was discussed at length with Peek and, following a visit to Winchester in 1998, a pair of 250 kHz transducers were loaned to the Project to see if these would improve the situation. Unfortunately this was not the case, and the transducers failed to provide any velocity data at all until they were eventually removed after some six different events. It had been hoped that the bigger transducers would provide more 'punch' to the sound signal, increasing the probability that it would be detected by the transducer on the far bank. It must be noted, however, that this was the first time that transducers of this size had been used with the Sarasota 1408 gauge; it is not yet known whether or not they would have worked under more favourable conditions than those encountered at Middleton.

Due to the limited amount of velocity data that were collected by the gauge during the study period, and the narrow range in levels over which the transducer paths were successfully operated, it was decided not to use the data to derive a stage discharge curve from a number of different stage velocity relationships. Results from other Project sites indicated that there has to be a significant difference in the different levels at which the velocity paths are operated for this approach to produce a notable improvement in the data.

It was thus decided to limit the analysis to comparing the flows produced by the gauge from three separate events, all using a single velocity path, to those produced by the Agency stage discharge relationship. The results are plotted as three time series in Figures 5.1 to 5.3.

Figure 5.1 shows the data collected from the velocity path deployed at 0.4 metres above stage datum. From this it can be seen that when the gauge was able to measure a path velocity the derived flow was very close to that derived from the Agency rating. Indeed, the maximum difference was 12%, for two 15-minute values, with more than 75% of the derived flows being within 5% of the Agency data. Interestingly, the flows on the rising limb of the first 'sub' event are very close, whilst those in the 'trough' between the two peaks are significantly different. If it is assumed that the ultrasonic gauge was working in a consistent manner throughout the whole event, this would suggest that there is a different stage-discharge relationship for rising and falling levels, i.e. hysteresis exists. Whilst this is probable, it must also be considered that the majority of flood gaugings are usually undertaken on the falling limb due to the practicalities of getting to sites and the stability of river levels. It would thus be expected that the Agency flows on the falling limb are more likely to be 'correct' than those derived when the river is rising; hence the close correlation between the ultrasonic and Agency flows when the river is rising is more likely to be fortuitous than real.

Figure 5.2 shows the flows derived from the velocity path deployed at 0.5 metres above stage datum. The same general points observed in Figure 5.1 are seen in Figure 5.2, but on an even greater scale. Having the velocity path at a higher level results in the difference between Agency and gauge flows being greater; this fact is further demonstrated by Figure 5.3 which is based on velocity data collected from 0.7 metres above stage datum.

This increase in difference is to be expected; as the velocity path is raised it will tend to record higher velocities, and thus exacerbate the discrepancy between Agency and gauge flows. Reference to Table 3.1 reminds us that peak levels during these events were all less than 1.38 metres; combining this with a mean bed level of -0.243 metres gives a maximum water depth of 1.623 metres (during the second event). The 0.4, 0.5 and 0.7 m velocity paths were deployed at 0.42, 0.48 and 0.60 of the maximum water depth during their respective events, with the velocity data being collected when the ratios were all much greater than this.

It may be possible to correct for this by using a power-law type relationship to represent the velocity profile using data collected from multi-path gauges. This would then allow a 'correction factor' to be applied to discharge data derived from a limited number of velocity paths. In the case of the Middleton data, this correction factor would be greater at low levels, and decrease for higher stages. At other sites, where the velocity paths were deployed at low levels, the reverse pattern might exist. It is intended that this issue will be explored in the final Project Technical Report.

Figure 5~~2~~4 Agency flows compared to those derived from the 0.4 m transducer path between 19/11/97 and 22/11/97

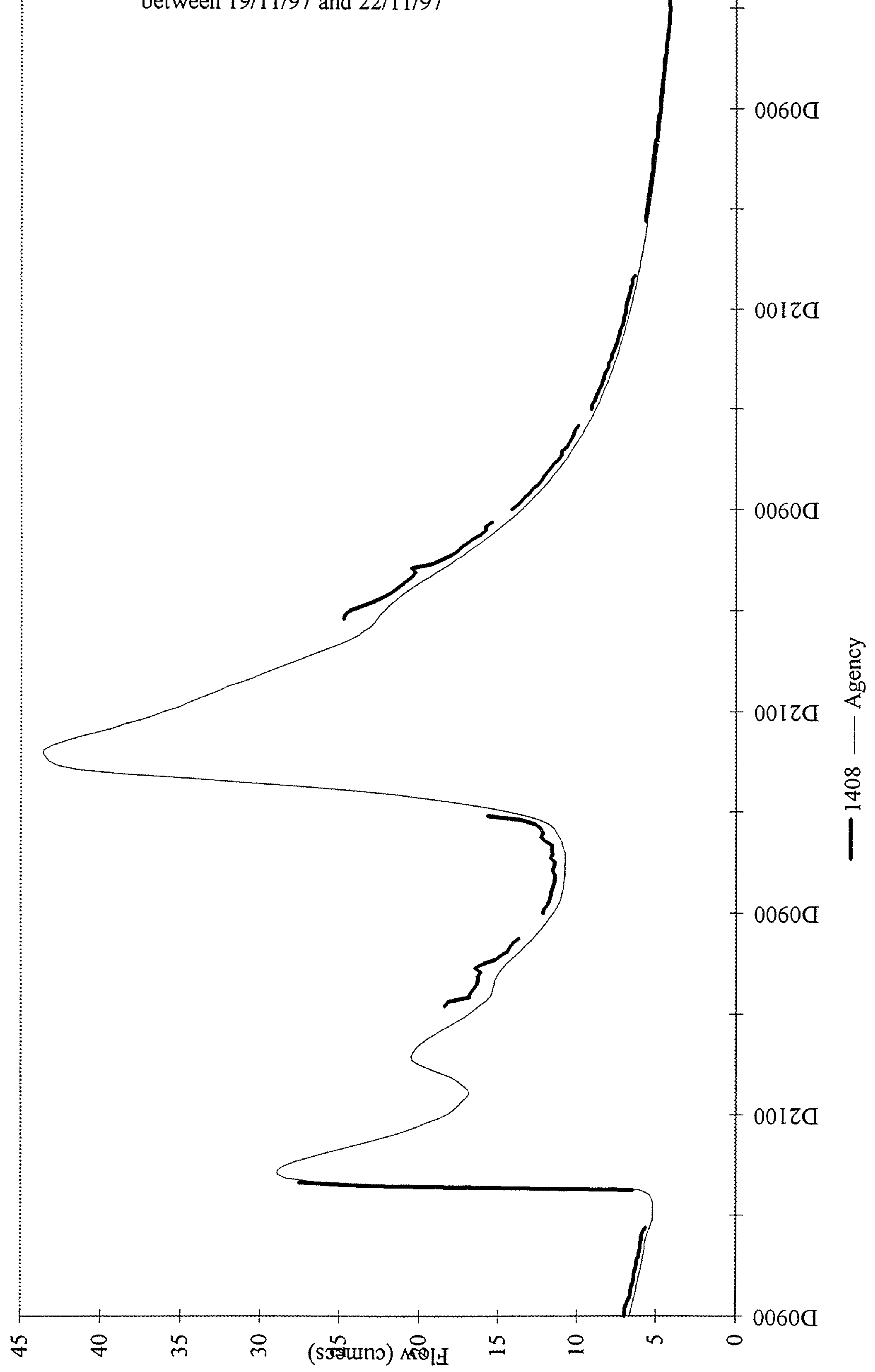


Figure 5.2 Agency flows compared to those derived from the 0.5 m transducer path between 21/01/98 and 23/01098

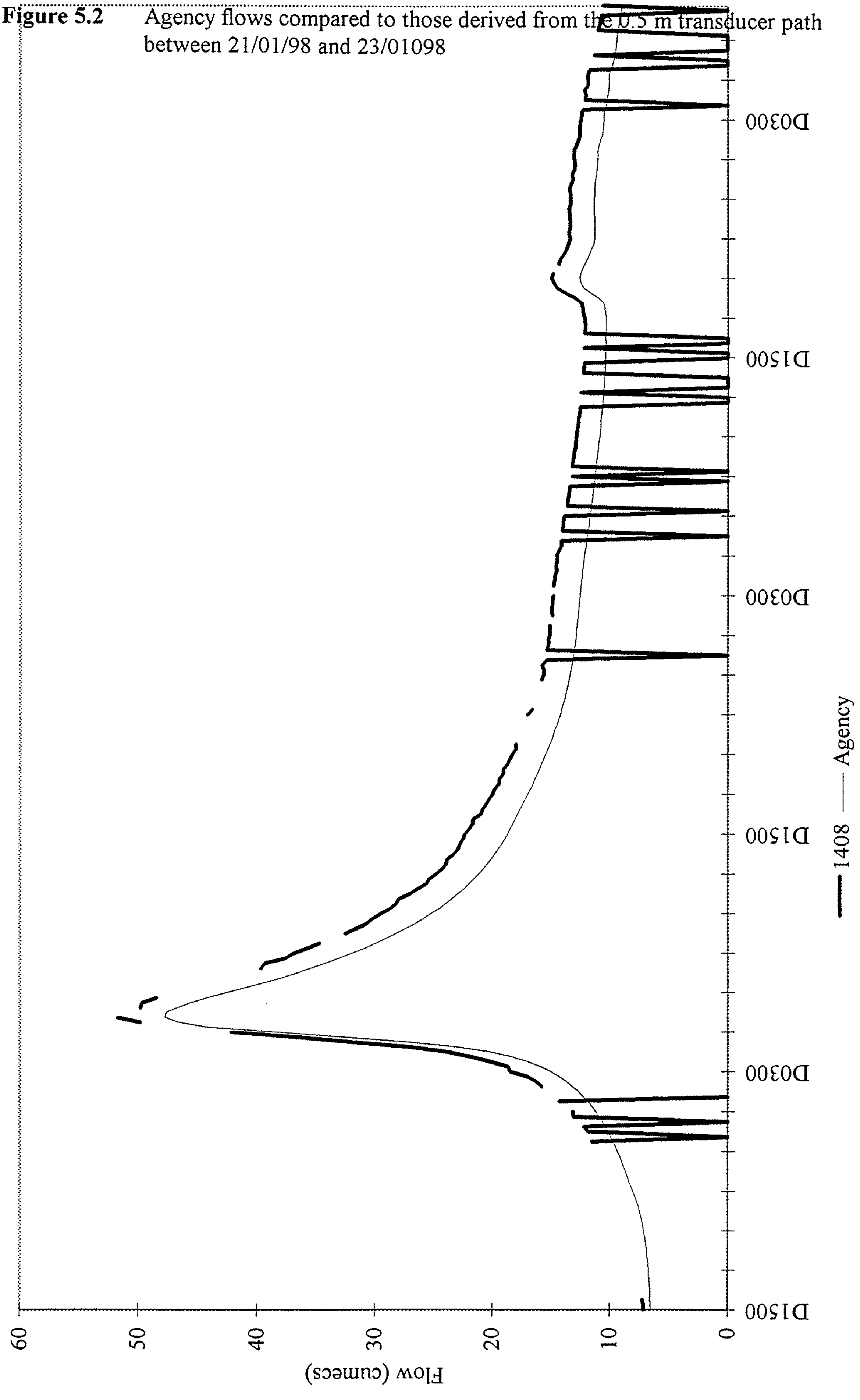
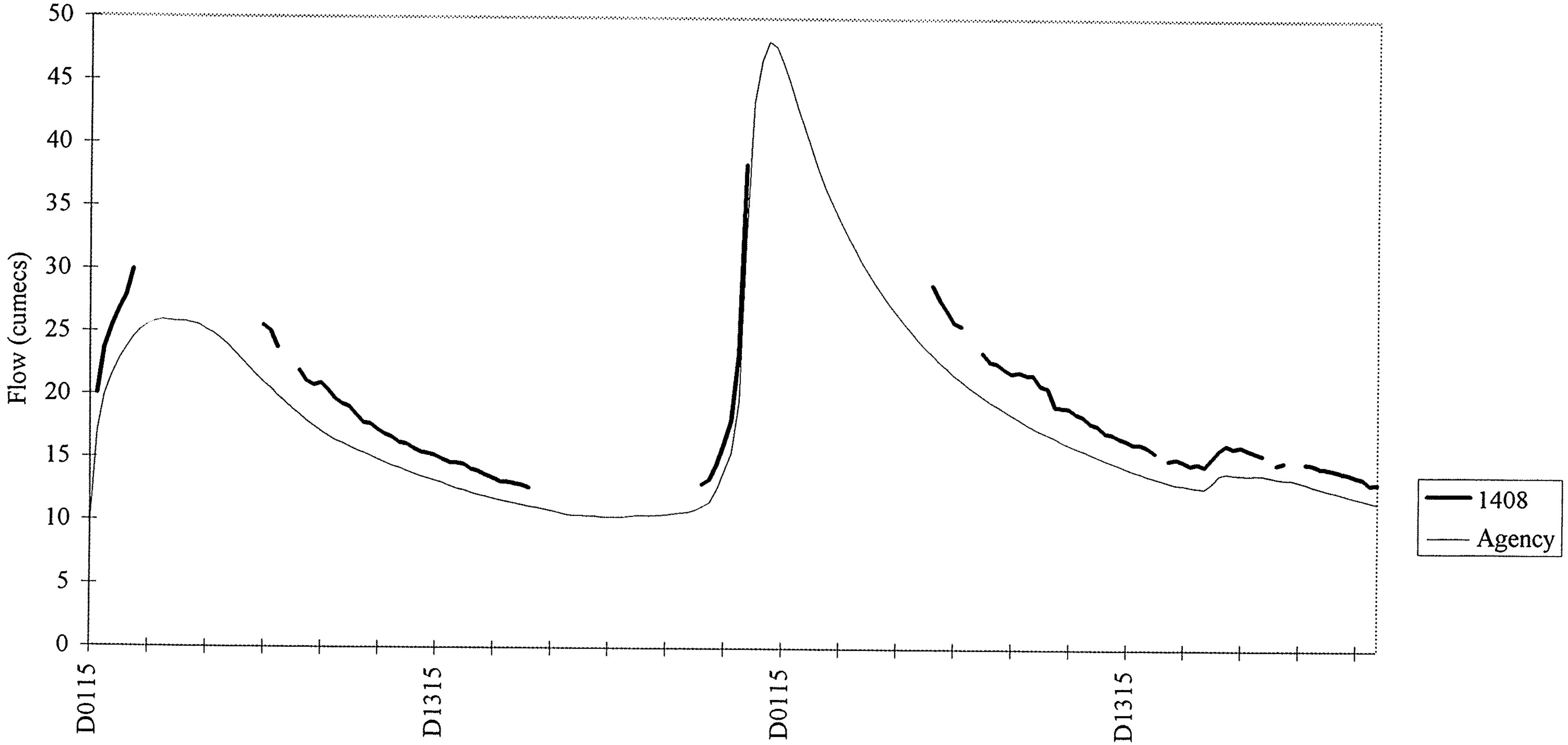


Figure 5.3 Flows derived by both the Agency stage discharge relationship and the 1408 ultrasonic gauge for the April 1998 event. The ultrasonic flow is based on velocities recorded along a path at 0.7 metres above stage datum.



6 DETERMINATION OF STAGE DISCHARGE RELATIONSHIPS

Although it was decided not to proceed with developing a stage discharge relationship based on multiple stage velocity relationships due to the limited range of velocity path levels from which it was possible to collect data, it is still possible to derive stage discharge relationships from the three events discussed in Section 5. These relationships are all plotted along with the Agency rating in Figures 6.1 to 6.3.

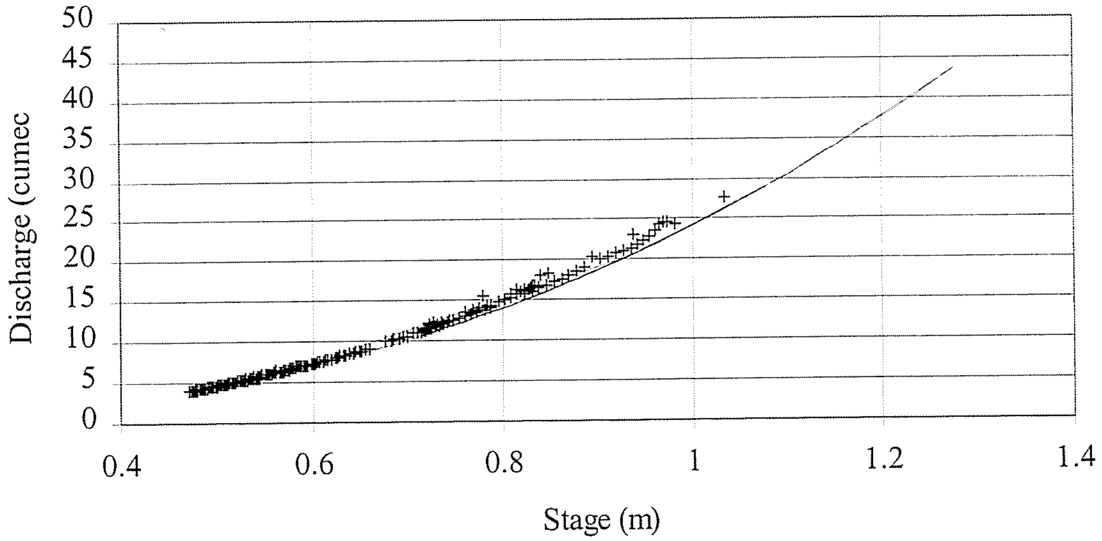


Figure 6.1 Agency stage discharge relationship plotted against that derived from the 0.4 metre velocity path.

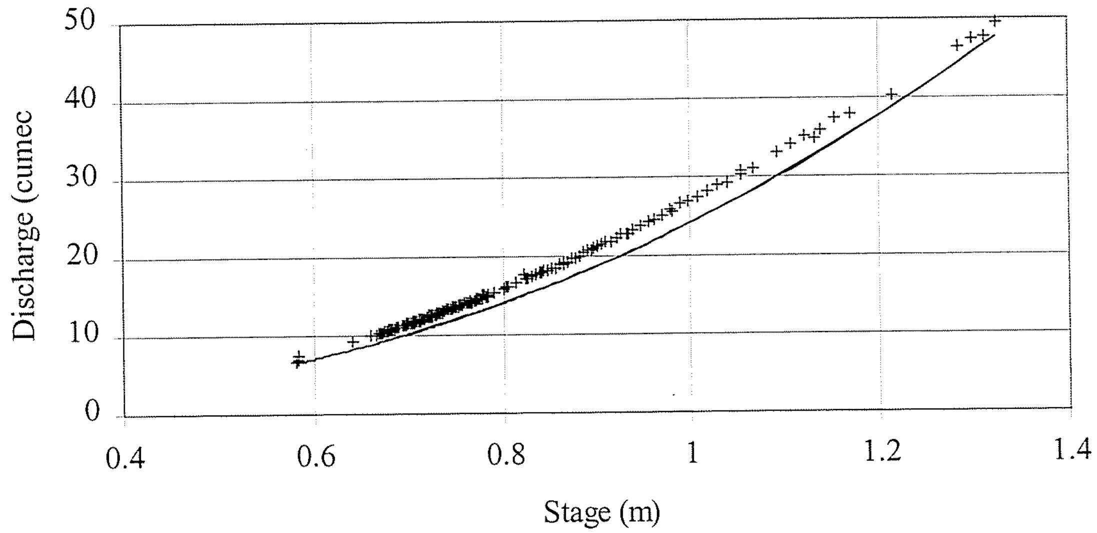


Figure 6.2 Agency stage discharge relationship plotted against that derived from the 0.5 metre velocity path.

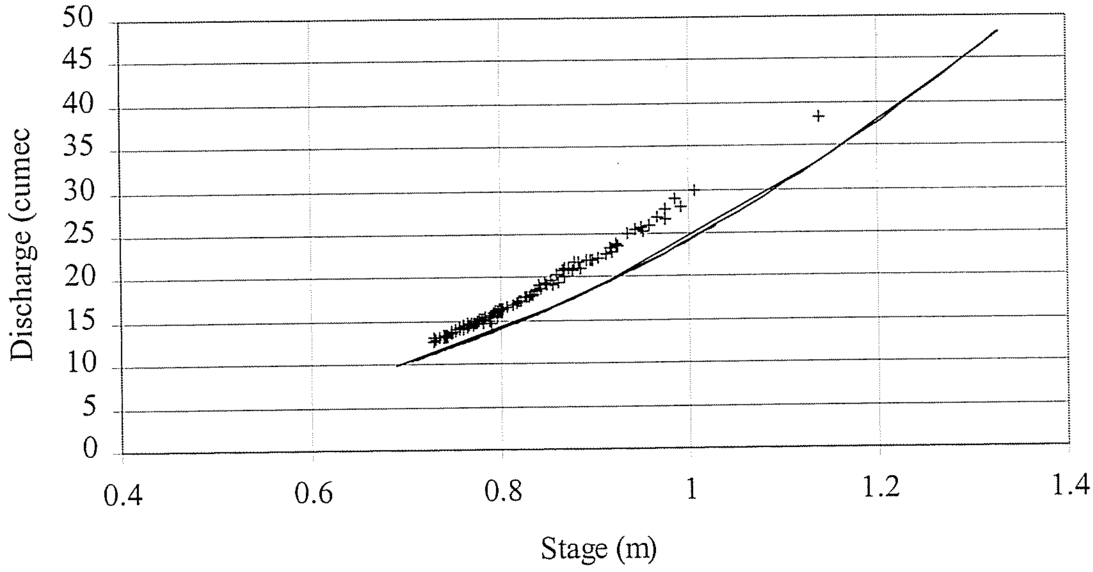


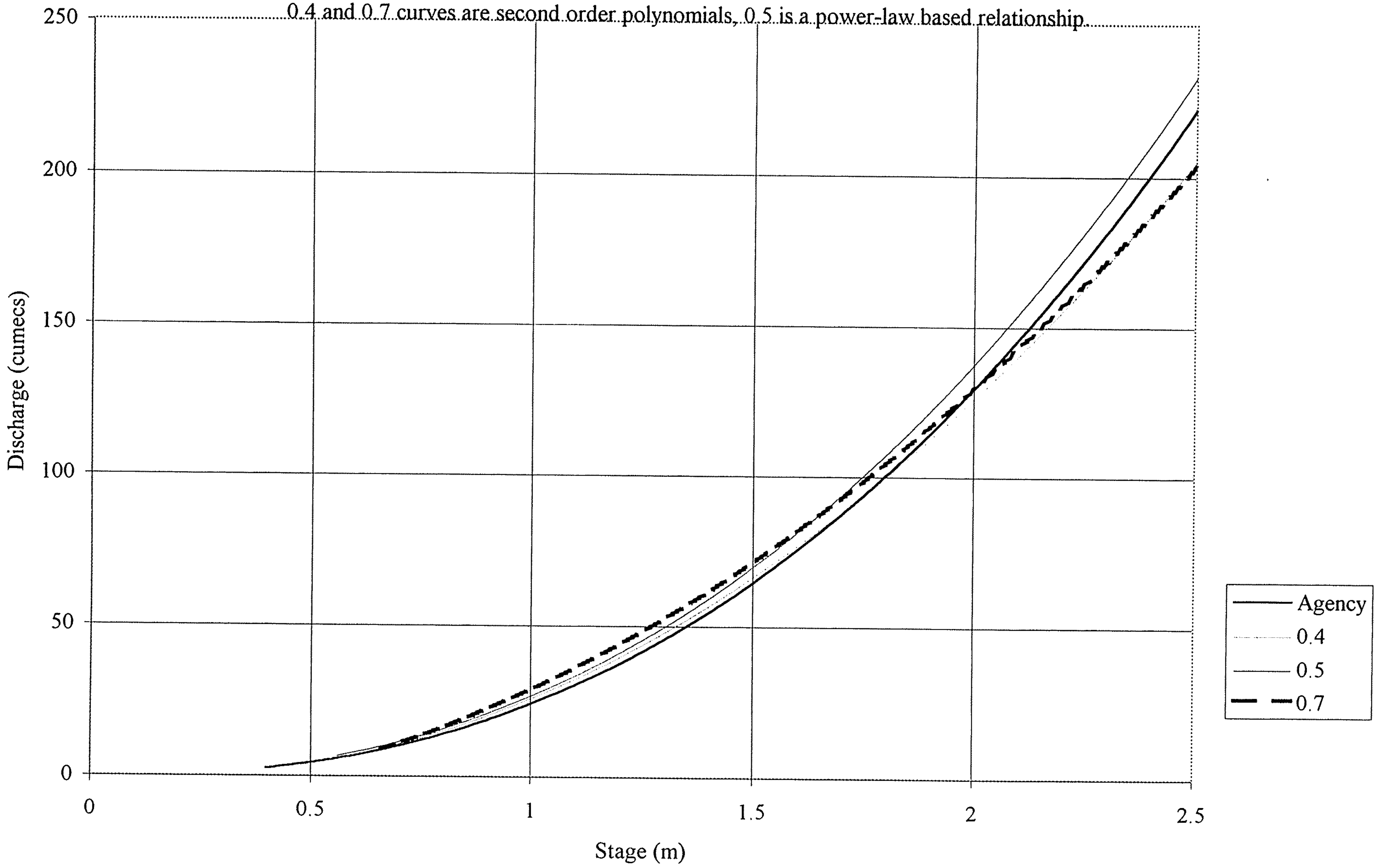
Figure 6.3 Agency stage discharge relationship plotted against that derived from the 0.7 metre velocity path.

Unsurprisingly Figures 6.1 to 6.3 all show the same general relationship as found in Figures 5.1 to 5.3, namely the data derived from the lowest velocity path are the closest to those derived by the Agency. In addition to this, Figures 6.1 to 6.3 show the differing nature of the individual relationships, the most striking feature being the tendency for the relationship derived from the gauge to become 'flatter' the higher the velocity path. Whilst this does not affect the goodness of fit between the two data series within the range of observed velocity data, it does influence the suitability of the relationship for extrapolating beyond this.

Best fit lines were fitted to all three sets of stage discharge data derived from the ultrasonic gauge; these are plotted in Figure 6.4, along with the Agency rating, for levels up to 2.5 metres above stage datum. It should be noted that second order polynomials were fitted to both the 0.4 and 0.7 metre datasets, whilst the 0.5 metre curve was a power-law based relationship. Appendix A shows each dataset together with the best fit power-law and polynomial curves for comparison.

It can be seen from Figure 6.4 that all three curves appear to closely follow the Agency relationship up to a stage of approximately 2.25 metres. Above this point the power-law derived relationship for the 0.5 metre curve is the only one that follows the same pattern as the Agency relationship, which is also based on a power law, whilst the polynomial curves of the 0.4 and 0.7 metres appear to significantly underestimate the flow beyond this point. Reference to Appendix A shows that the selected curves appear to be the best ones for each data series which leads to the conclusion that, as with other sites, it is important to consider the type of statistical fit being used to extend a data series.

Figure 6.4 Stage discharge relationships derived from the three sets of velocity data plotted against the Agency rating for Middleton in Teesdale.



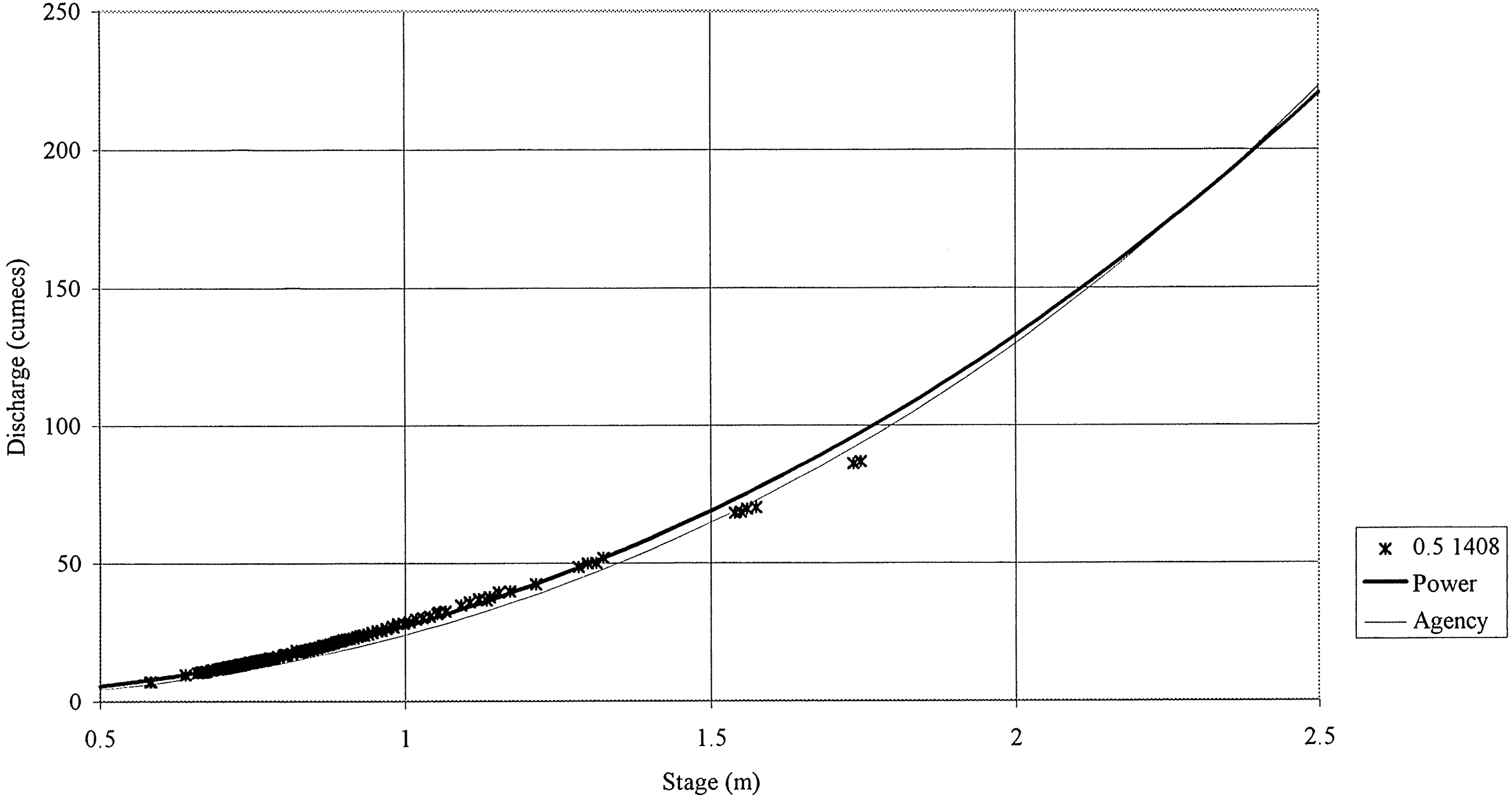
Even if the use of the polynomials is accepted as being less preferable to a suitable power law equation, when based on suitable data, Figure 6.4 would suggest that it is reasonable to extend the derived rating curve to over twice the observed range in levels. At a stage of 2.25 metres all four ratings are within 5% of each other.

Close study of the curves in Appendix A shows that there appears to be a 'break' in the stage-discharge relationship at a stage of approximately 1.0 to 1.1 metres; the break corresponding to a lower discharge than would have been expected from the data collected at lower levels. This is particularly noticeable in the 0.5 and 0.7 metres plots. This stage corresponds to the point where the river begins to flow out of channel on the near bank, at which point there may well be a decrease in the water velocity due to increased edge effects. This may explain why it is the 0.5 metre dataset, which included velocity data collected at a stage of between 0.2 and 0.3 metres higher, is the one which appears to best match the Agency rating curve.

The issue of extrapolation can be further explored using the 0.5 metre velocity path data. Whilst the gauge repeatedly failed at high river levels, the event which occurred between the 8th and 12th January 1998 did provide very limited velocity data from higher river levels; a total of six velocity readings were obtained for stages between 1.5 and 1.75 metres above stage datum. (It is thought that the very rapid rise in water levels may have enabled the gauge to 'snatch' some velocity data before the more 'murky' water from the upper catchment arrived at the site).

Discharge data were derived from these six readings, and they are plotted on Figure 6.5, together with the power law ratings derived from the data and the Agency. It can be seen from this that the addition of a very small number of points in the upper part of the flow regime results in the two rating curves being much closer throughout the upper regime than those presented in Figure 6.4, confirming the findings of earlier site studies that it is important to try and collect data over as wide a range of levels as possible. Indeed, the results from Middleton indicate that the range of river levels over which the velocity data are collected is more important than the number of paths or the height of these paths. Figure 6.4 also shows that, at higher stages, the gauge begins to underestimate the Agency rating. This can be explained by the fact that the gauge will, at higher levels, only be calculating the flow for part of the channel, and there will be additional water flowing outside the section covered by the transducer path.

Figure 6.5 Power law rating curves for Mideleton in Teesdale based on the complete 0.5 metre velocity path dataset and the Agency rating.



7 CONCLUSIONS

Whilst the ultrasonic gauge struggled to operate at Middelton in Teesdale due to the site conditions, most likely high suspended sediment concentrations, the studies have provided a number of useful results to the Project. These include:

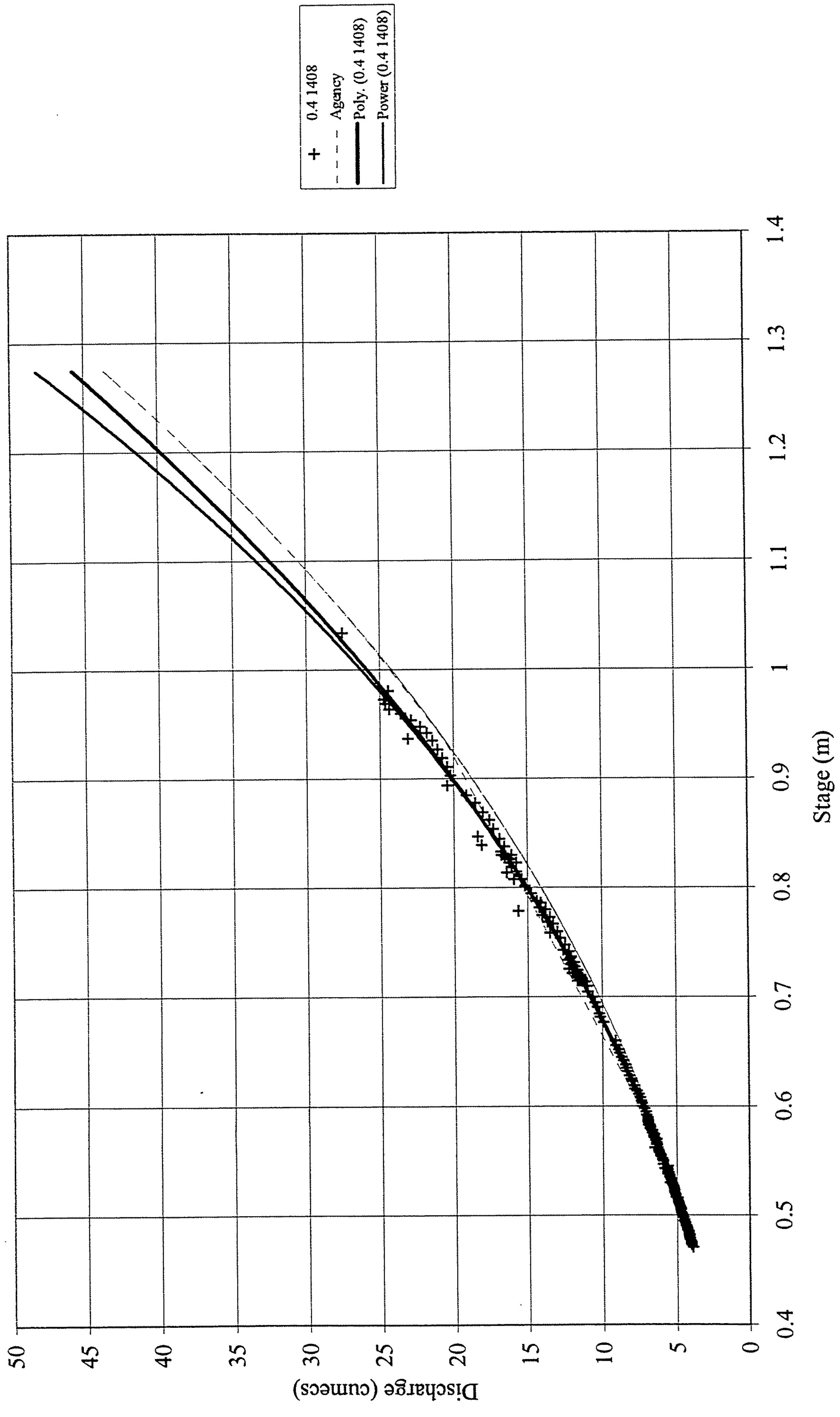
1. It is possible to undertake an installation at 'difficult' sites in a reasonable timescale, and to install the equipment such that it is able to withstand very high flow conditions.
2. The gauge is able to measure river level during a very rapidly rising stage, with the measurements correlating very closely to those recorded by the Agency equipment.
3. There were notable differences in recorded levels during some of the events; it is not possible to confirm which of the two instruments was recording the 'correct' level without referring to chart levels for specific events.
4. Whilst it is accepted that the gauge struggled to measure velocities during high flow events, the study results indicate that when measurements were successfully made they were both consistent and realistic.
5. The gauge configuration used at Middleton consistently produced derived flows which were higher than those produced by the Agency rating. This was to be expected given the relatively high height at which the transducer paths were deployed. There are a number of ways in which this overestimation could be overcome, including the establishment of a correction factor based on the velocity distribution, or adjusting the bed correction factor (which was set at 0.65 at Middleton). The Greenholme studies that the latter option could significantly improve results.
6. It was possible to use the gauge data to successfully derive stage-discharge relationships for the site. These relationships could be extended to over twice the observed range and still produce acceptable (ie within 10%) estimated of flow.
7. The availability of extremely limited data from higher levels enabled the stage discharge rating derived from the gauge data to be extended even further whilst still producing acceptable results. At a stage of 2.5 metres the Agency and gauge flows were 223 and 221 cumecs respectively, less than 1% apart.

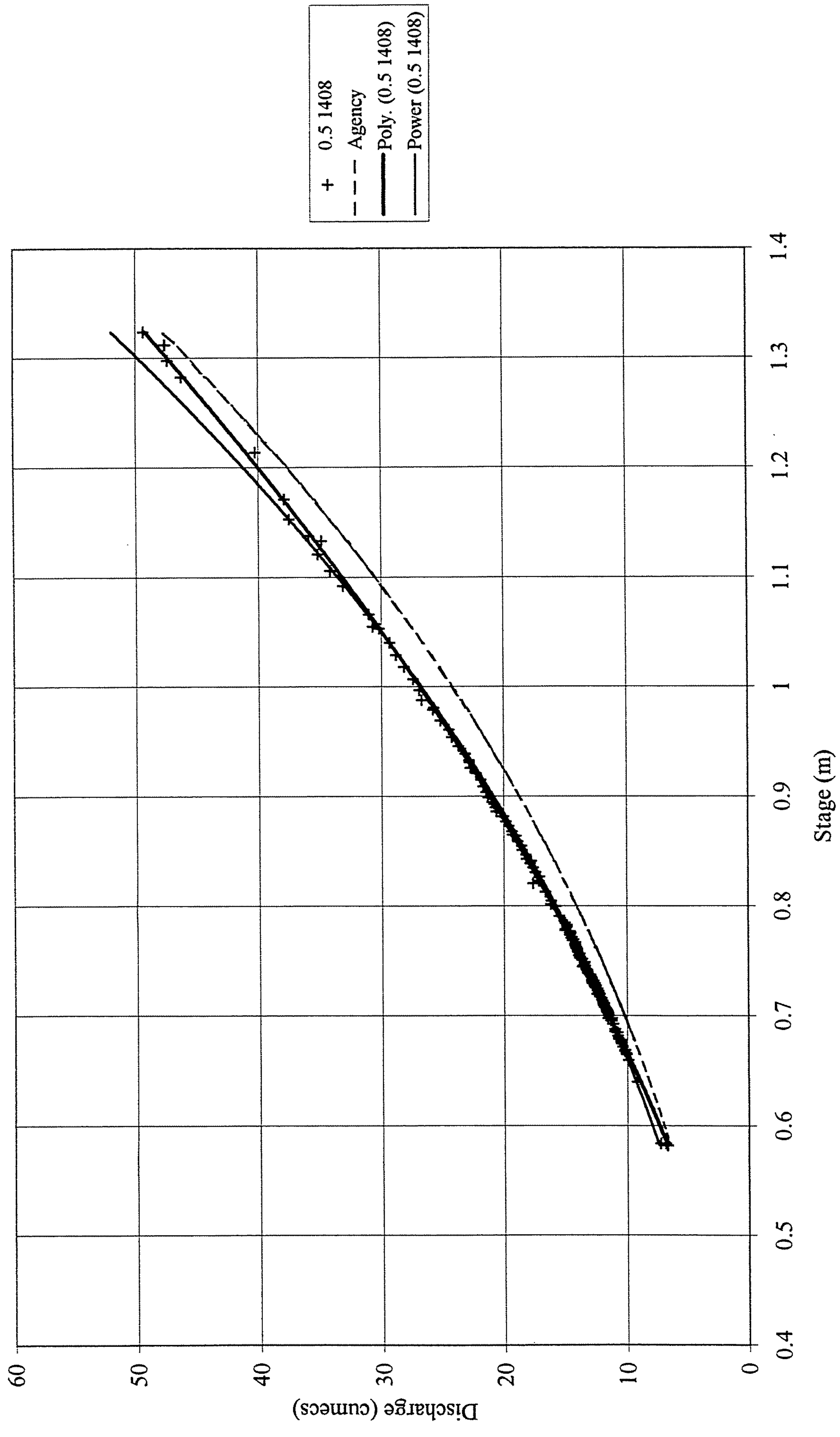
Finally, it must be remembered that the problems encountered with the equipment may be linked to the equipment as well as the site conditions. Other suppliers have equipment currently on the market that has automatic gain settings; potentially this could overcome the problems caused by suspended sediment loads at sites such as Middleton.

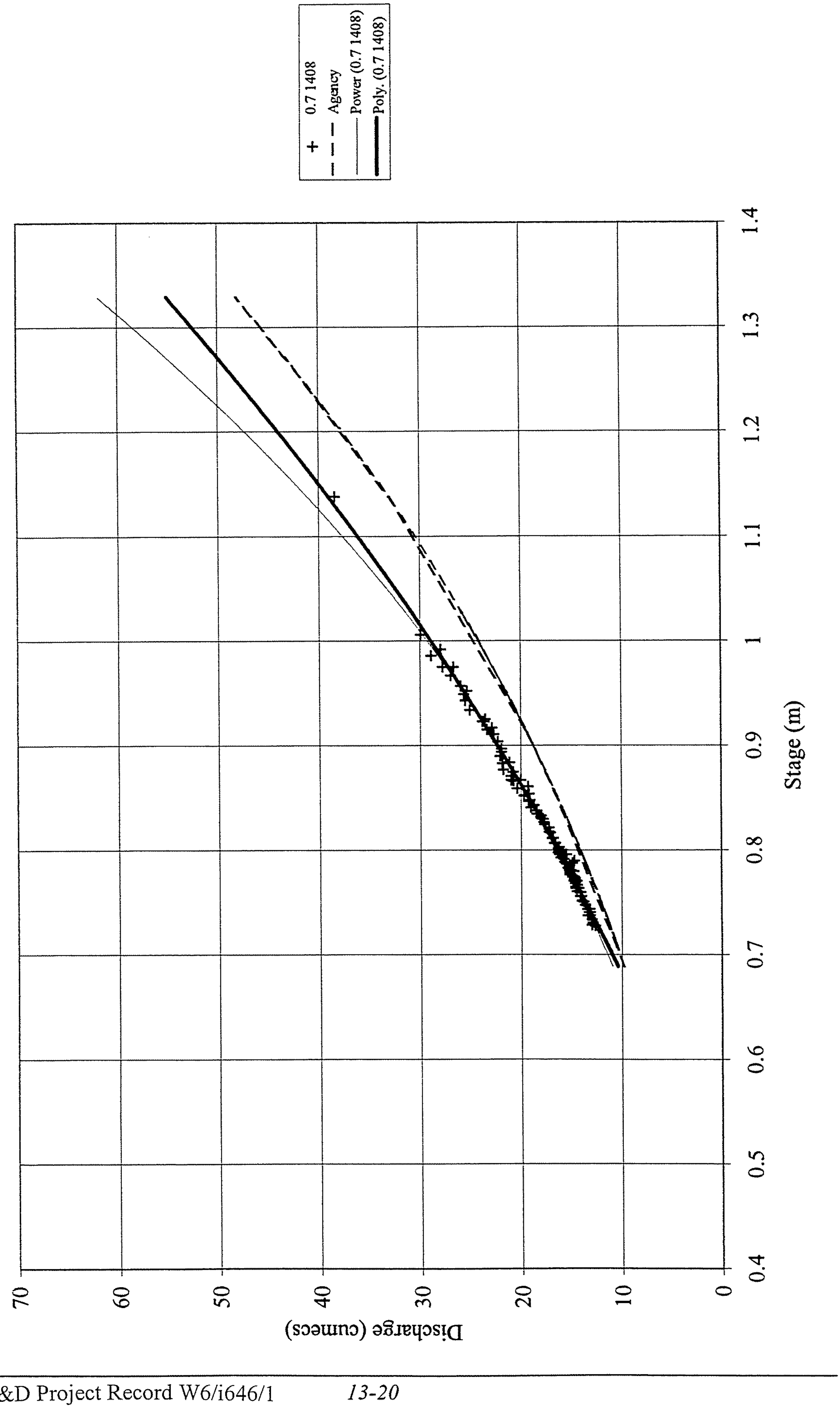
APPENDIX A

Stage discharge relationships derived from the transducer path data collected at Middleton In Teesdale gauging station between March 1997 and December 1998.

Best fit power-law and second order polynomials are plotted, together with the Agency stage discharge relationship for the site.


0.4 1408
Agency
Poly. (0.4 1408)
Power (0.4 1408)
Discharge (cumecs)
0
5
10
15
20
25
30
35
40
45
50
Stage (m)
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4


+ 0.5 1408
Agency
Poly. (0.5 1408)
Power (0.5 1408)
Discharge (cumecs)
0
10
20
30
40
50
60
Stage (m)
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4


0.7 1408
Agency
Power (0.7 1408)
Poly. (0.7 1408)
Discharge (cumecs)
0
10
20
30
40
50
60
70
Stage (m)
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4

14 WALCOT SITE REPORT

1 INTRODUCTION

Walcot gauging station is used by the Midlands Region of the Environment Agency to monitor flows on the River Tern, upstream of its confluence with the River Severn. The catchment has low relief and the landuse is predominantly agricultural, although there are a number of industrial abstractions and discharges upstream of the site. the site is subject to severe weed growth in summer months, which has caused some problems with the rating at the site.

The station was initially rated as an open-channel section before being upgraded with a temporary gabion control in 1976. This was replaced two years later with a 15 metre wide flat V weir built to British Standard specification with very high wing walls and a crest tapping. The cableway was retained for high flow and calibration gaugings.

Walcot was chosen as a field study site for this project for the following reasons:

- The Agency had recently commissioned an automatic flushing system for the crest tapping at Walcot. This has allowed them to collect what is thought to be accurate data during non-modular conditions. Richard Iredale has agreed to send us copies of the data once it has been processed to allow a three-way comparison to be made between 1408, theoretical and stage/discharge derived values for non-modular flows.

- The catchment experiences a wide range in flows, and has a medium-long response time to significant rainfall events ensuring that it should be possible to get to the site during high flows (travel time from base was approximately 4 hours).

- Analysis of previous records indicated that a 'typical' winter would produce a number of significant high flow events.

- Variable hydraulic conditions in the channel due to upstream and downstream weed growth, and possible backing up from the River Severn, would ensure that the sensitivity of the gauge would be tested.

- This was the only site chosen for use during the project that had a known weed problem - how would this affect the performance of the gauge?

- The approach channel was both straight and of reasonably uniform gradient, providing suitable conditions for gauge deployment.

- The weir has a reasonably high P_1 value of 0.7 metres (difference in elevation between the notch in the weir and the mean bed level). Would this affect the performance of the gauge?

- Finally, it was hoped that as the upstream channel was so uniform, with a slow moving and even river, the reflector trials that were being carried out at Lea Hall could be extended to include Walcot.

2 GAUGE INSTALLATION

The Walcot installation was completed on 22 November 1996, although at that time there was still a problem with the unit's visual display board that had been detected at Lea Hall; this was replaced on the next visit on December 4. As with other field sites the transducers were lined up by sight rather than oscilloscope, and counts of 255 were obtained at the first attempt. The installation took a total of 31 hours to complete, with the presence of a footbridge over the weir crest aiding this. The footbridge was used to support the co-axial cables, the routing of which was the most time consuming aspect of the installation.

Due to the anticipated high range in levels at the site four sets of velocity path transducers were installed on 3 metre high racks, although only two could be connected to the gauge at any one time. This would enabled the gauge to be reconfigured to collect data from different levels from the safety of the gauging station during high flows. The installation enabled the collection of data from paths as much as 2.5 metres apart should it be required. Figure 2.1 shows the layout of the gauge components at the site.

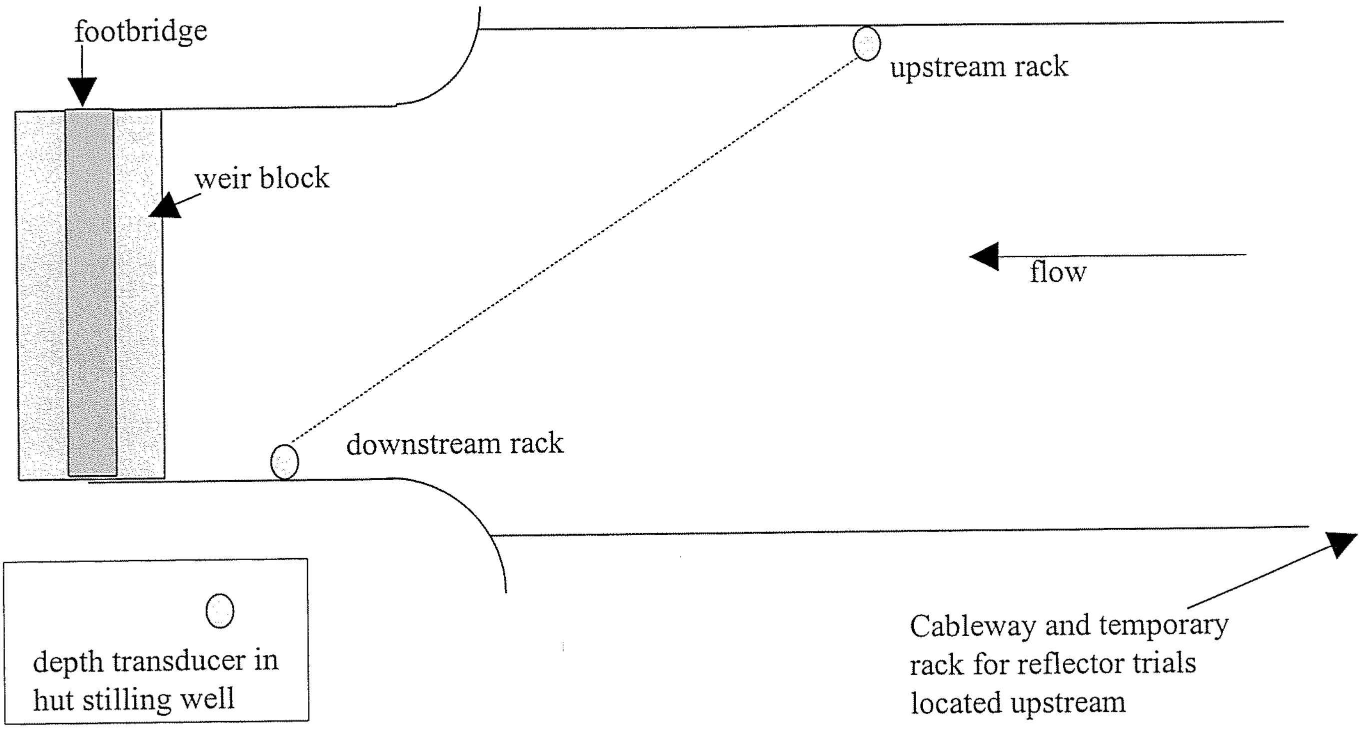


Figure 2.1 Schematic diagram to show the layout of the gauge components at Walcot gauging station (not to scale). The footbridge was used to convey the cables from the far bank.

3 EVENTS RECORDED AT THE SITE

Despite a drier than normal winter for the second year running, a number of high and low flow events were recorded at Walcot. Data from these events are contained in the disc which accompanies this Project Record. For the purposes of this Site Report the events listed in Table 3.1 will form the main focus of the data analysis.

Table 3.1 Summary details of the five data sets used for the assessment of the gauge performance at Walcot.

Start date of event	Transducer path levels (m)	Minimum stage (m)	Maximum stage (m)
18/12/96	-0.1, 0.2	0.403	1.413
27/11/97	0.1, 0.2	0.464	1.185
1/1/98	0.5, 0.8	0.777	1.930
10/4/98	Assessment of crest tapping blockage - various levels		
16/9/98	Various - reflector trials		

4 GAUGE PERFROMANCE - RELIABILITY

The 1408 gauge was installed for almost two years at Walcot. During this period, when it was unattended for a prolonged period due to the project officially being in a state of dormancy whilst awaiting high flows, the gauge performed faultlessly. The only problem that was encountered associated with the gauge hardware was the initial failure of the LCD panel, a fault inherited from Lea Hall and one which Peek quickly rectified.

Whilst the actual gauge components performed well, it was found that that the weed growth in the channel did result in the gauge not being able to work reliably during the late summer months. As soon as weed was cleared from the channel, either manually or by a high flow event, the gauge was able to quickly recommission itself once again.

The depth transducer was installed in the stilling well at Walcot. Whilst this configuration worked throughout the study period, it was noted that the depths recorded by the gauge and Agency equipment often differed, sometimes by as much as 20 mm. It is felt that the most likely cause for this is the difference in temperature between the water in the well and that in the river where the velocities were being recorded, further confirming the conclusions reached at other sites that, if possible, the depth transducer should be installed directly in the river channel.

5 GAUGE PERFORMANCE - FLOW MEASUREMENT

The studies completed at Walcot confirmed the occurrence of variable hydraulic conditions in the channel depending on the antecedent weed growth and flows. Consequently, no stable stage-discharge or stage-velocity relationship was found for the site, unlike the majority of the others used for the project. Chapter 6 in the Technical Report addresses this issue using Walcot as a case study; this analysis is repeated here as it is the most thorough assessment of gauge performance at the site that was completed during the project

Whilst a theoretical rating curve has been determined for the site based on the British Standard, current meter gauging from a cableway upstream of the wing walls indicates that the flows produced by the rating do not match up to the gauged flows under certain conditions. Two reasons have been identified for this:

1. Both the upstream and downstream channels are subject to considerable weed growth during the summer and autumn months, leading to differences between theoretical and gauged flows at low-medium flows.
2. During prolonged wet periods the channel backs up. The causes of this include both downstream channel constrictions and the River Severn.

5.1 Assessment of stage-velocity relationships

Non-modular conditions are defined by British Standard 3680: Part 1: 1991 as *the flow, over or through a structure, which is drowned when it is affected by changes in the level downstream.* Under such conditions the channel becomes less efficient, ie the flow over the weir is less than would be expected according to the weir formula. For this to happen the mean channel velocity must be less than the theoretical value.

To establish whether or not this reduction in weir efficiency occurs, and to quantify the extent to which the flows are affected, two approaches have traditionally been used. The first of these, which is at present only applicable to horizontal Crump weirs, depends on the ratio between the downstream and upstream water levels. The second utilises the crest tapping, and can be used at both horizontal and flat V Crump weirs, and depends on the ratio between the measured head at the crest tapping and that upstream of the weir block.

Rather than use an 'indirect' or surrogate measure of changing velocity conditions, the ultrasonic gauge offers the opportunity to directly monitor the relationship between stage and velocity in real time. To illustrate this, Figure 5.1 plots stage against velocity for the first high flow event that was recorded at Walcot.
A clear break in the stage-velocity plots can be seen at a stage of approximately 0.6 metres above weir crest invert in Figure 5.1. Above this point the rate of increase in path velocity decreases, suggesting that the weir becomes less efficient at this point. It is worth noting that whilst path velocities continue to rise, the peak mean velocity of 0.75 m/s is by no means large.

In addition to demonstrating that the ultrasonic gauge is able to detect any changes in the stage velocity relationship, the data presented in Figure 5.1 also provide confirmation of the modular limit for the weir. Prior to this event, which was the first significant one to yield data from the crest tapping, the Agency had considered the limit to be at a stage of 0.8 metres. Analysis of the crest tapping data following the event indicated that the modular limit was lower than this, with a 5% reduction in theoretical flows being calculated for a stage of 0.6 metres. This coincides very closely with the break in the stage velocity relationships plotted in Figure 5.1.

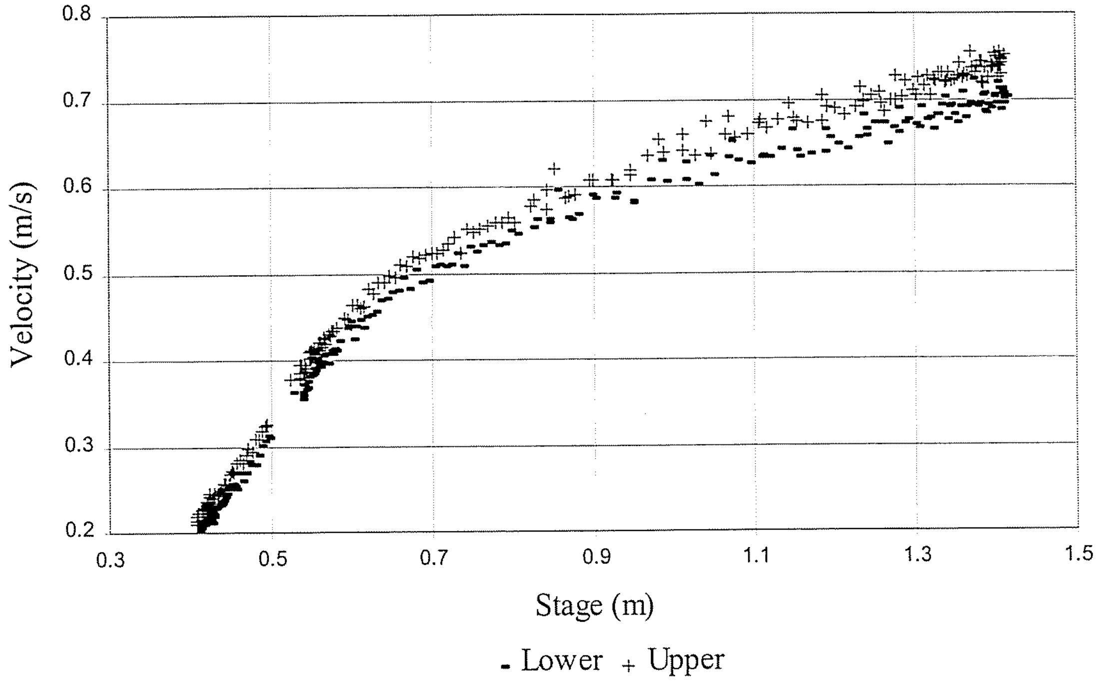


Figure 5.1 Stage plotted against velocity for the event recorded at Walcot between 18th and 20th December 1996. The upper and lower transducer paths were deployed at 0.2 and -0.1 metres above the weir invert respectively.

Having confirmed that the ultrasonic gauge is able to identify that non-modular flows occur, and that it appears to be sensitive enough to be able to quantify the modular limit, the final issue to be discussed regarding stage-velocity relationships is their consistency. Whilst the information presented in Figure 5.1 confirms the occurrence of non-modular flows, it could be argued that if the modular limit consistently occurs at a fixed stage then the weir could be regarded as a stable open channel section and be calibrated by current meter gauging above the modular limit. In order to assess whether or not this is possible it is necessary to compare the stage-velocity plots derived from data collected during different events. Ideally this would involve velocity data collected during both summer and winter months, and from the same level in the river. Unfortunately, no summer data were collected from the site, primarily because the main focus of this Project was high flows and field work was thus concentrated in the winter months, but also because weed growth caused difficulties in getting the velocity paths to function. It is thus necessary to use velocity data that were collected from similar levels (0.1 and 0.2 m above weir invert) during two events that occurred at similar times of the year (December 1996 and November 1997). These data are plotted in Figure 5.2.

It can be seen from Figure 5.2 that whilst the data collected during the two events may display a similar pattern in that both plots have a break in slope that is caused by the onset of non-modular conditions, the detail is somewhat different for the two series. The 1996 data appear to demonstrate a sharper break, at a stage of 0.6 metres as discussed above. In contrast, the 1997 curve does not begin to level off until a stage of 0.7 metres, and even then the curve continues to flatten progressively, rather than forming a near-linear relationship like the 1996 data. The data recorded during the two events would thus seem to indicate that the stage-velocity relationships differ from event to event.

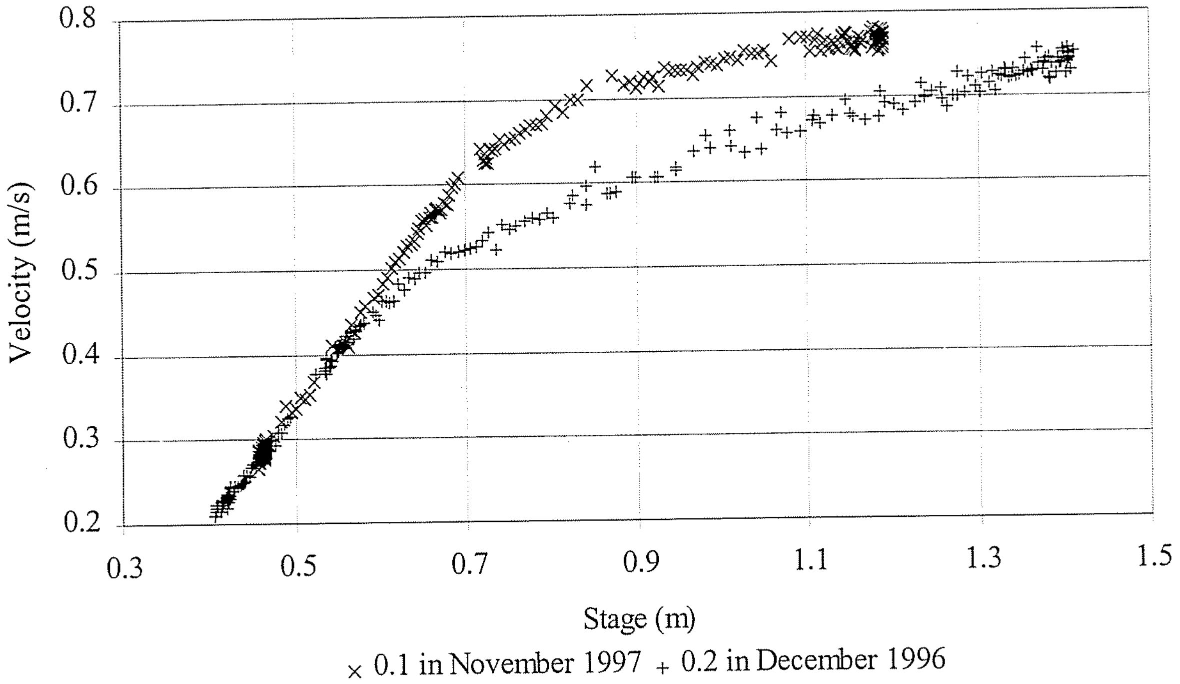


Figure 5.2 Stage-velocity data collected from two different events at Walcot. x indicates values collected from a velocity path deployed at 0.1 metres above the weir crest between 27th and 29th November 1997, whilst + indicates the data collected from a path 0.2 metres above the weir crest between 18th and 20th December 1996.

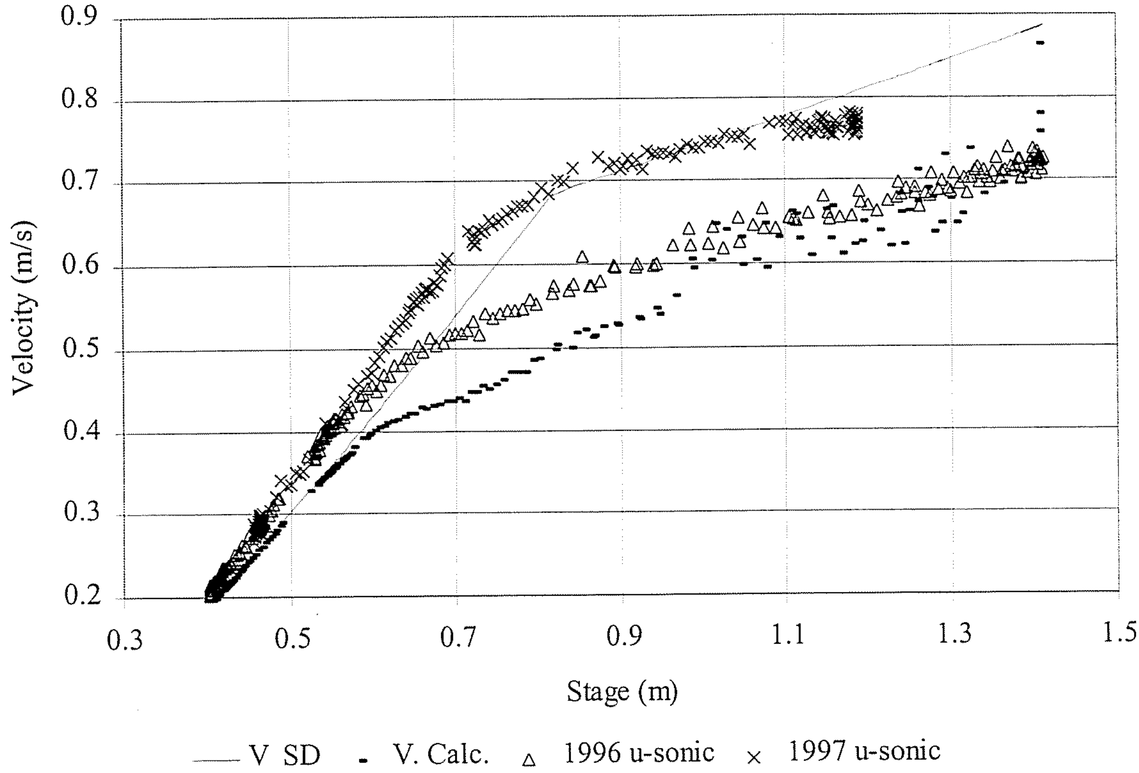


Figure 5.3 Velocity data recorded by the ultrasonic gauge during the 1996 and 1997 events at Walcot plotted with mean channel velocities derived from the stage discharge rating for the site (V SD) and the those derived from the corrected non-modular flows for the 1996 event (V. Calc.).

Whilst it might be argued that using velocity data collected from two different levels may be a contributory factor to the differing relationships, it can be seen from Figure 5.1 that data collected from different levels but during the same event follow the same pattern. Furthermore, the 1997 data plotted in Figure 5.2 were collected from a path that was lower than that of the 1996 data series (but still lying between the two 1996 velocity paths) and yet produces higher velocities above the modular limit. It is thus considered to be unlikely that the differences in the two data series plotted in Figure 5.2 are due to the differing path levels, but indicate a true difference in the stage-velocity relationship. A further point to note is that the potential range of the modular limit during the 1997 event (between 0.7 and 0.9 m above weir invert) spans the 0.8 m value that the Agency previously considered to be the point of departure from the weir equation. This is further illustrated in Figure 5.3 which shows the gauge velocity data from the two events, together with that from the Agency stage-discharge curve for the site, and the mean channel velocities calculated from the corrected flows (using the crest tapping approach) for the 1996 event. It can be seen that whilst the 1997 data follow a similar pattern to that produced by the stage discharge rating, the 1996 gauge data follow that derived from the corrected flows. The relationship between the two 1996 data sets is so strong that it is possible to observe a single path from the gauge over-representing true channel velocity during the lower part of the stage, but tending to under represent true velocities as the river rises.

It can thus be seen that had a single stage-discharge relationship been used to calculate flows at Walcot for the two events there would be systematic errors in at least one of the resulting hydrographs. In order to derive accurate flows at a site such as this it is thus necessary to monitor conditions *in situ*, be it velocity or another parameter.

5.2 Deriving flows

Having demonstrated the usefulness of monitoring velocities *in situ*, the next step in the assessment of operating the gauges in real time is to evaluate their performance at deriving flows. However, as the previous section has demonstrated, in order to do this it is necessary to have a reliable means of deriving the true flow. Whilst it is assumed that the flows produced by the crest tapping/upstream head method are as accurate as can be, there are still considerable uncertainties associated with this approach.

Two events were selected to assess the suitability of the ultrasonic gauge for measuring flows in real time at Walcot. The first of these events was between the 18th and 26th December 1996, and included the velocity data presented in section 5.1. The velocity paths were deployed at a level of -0.1 and 0.2 metres above weir invert, and would thus be expected to under-measure peak velocities as the peak water level was over 1.4 metres above weir invert (mean bed level was 0.7 metres below weir invert). The data for this event are shown in Figure 5.4. **Note that the flows derived by the ultrasonic gauge (for both events) are as recorded; no transformation of any kind has been applied to the data, or adjustments made to mean bed level, bed correction factor etc.**

It can be seen from Figure 5.4 that, for the vast majority of the event, the flows recorded by the ultrasonic gauge closely match those derived from adjusting the weir equation using the crest tapping data. It is only at the peak of the event that there is any significant difference between the two curves, with the ultrasonic gauge calculating lower flows than the adjusted weir formula for part of the time, although the two curves do coincide for some of the values. Note that during these peak flows the iteration used to correct for non-modular conditions is not able to function 100% of the time. This is a known and documented weakness of this particular approach. One further point that can be made about the flows derived by the adjusted weir equation is how 'jumpy' they are, particularly during the peak of the event. The ultrasonic gauge data suggests that this fluctuation is not real but is a result of the iteration which is very sensitive to minor fluctuations in the crest tapping levels as the crest/upstream head ratio increases.

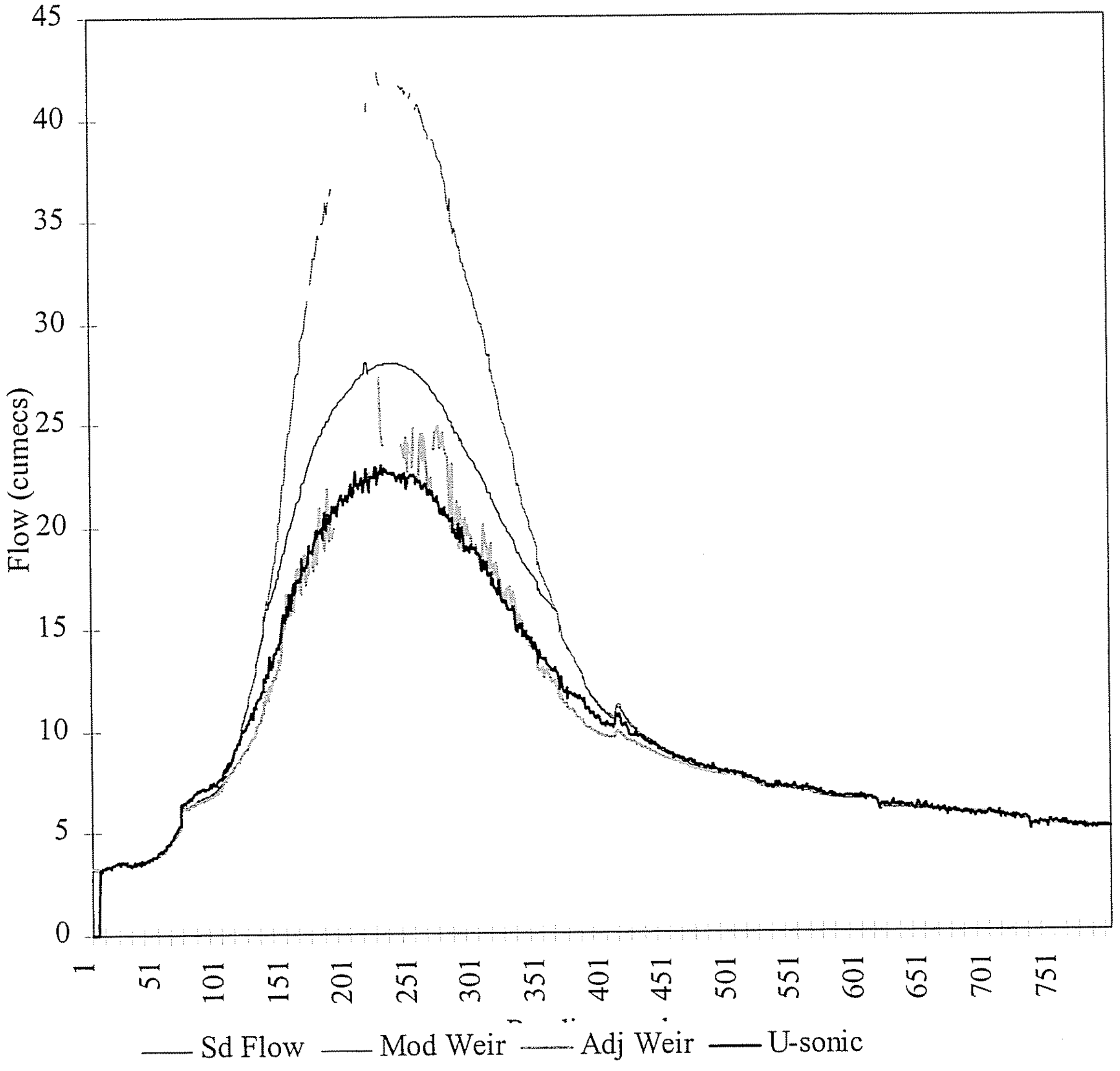


Figure 5.4 Flows at Walcot gauging station recorded between the 18th and 26th December 1996 inclusive. Sd flows are those produced by the Agency rating, Mod Weir are those from the modular weir equation, Adj Weir are the flows calculated from the crest tapping/upstream head ratio, and U-sonic are the flows recorded by the ultrasonic gauge with velocity paths deployed at -0.1 and 0.2 metres above weir invert. Note that due to the nature of the processing iterations it was not possible to calculate Adj Weir flows throughout the entire event.

The stage-discharge rating developed and used by the Agency appears to over-estimate flows during this particular event by as much as 5 cumecs (approximately 25% of the true peak) compared to both the ultrasonic gauge and adjusted weir formula, whilst the modular weir equation (which is **not** used at this particular site, but is employed elsewhere by other Agency Regions) produces peak flows more than twice the magnitude of the adjusted weir equation. For reasons that will become apparent later in this chapter there is little more that can be inferred from the flow data presented in Figure 5.4. Figure 5.5 shows the hydrographs produced by the Agency rating, adjusted weir formula (where possible) and the ultrasonic gauge with the velocity paths deployed at 0.5 and 0.8 metres above the weir invert between January 1st and 8th 1998.

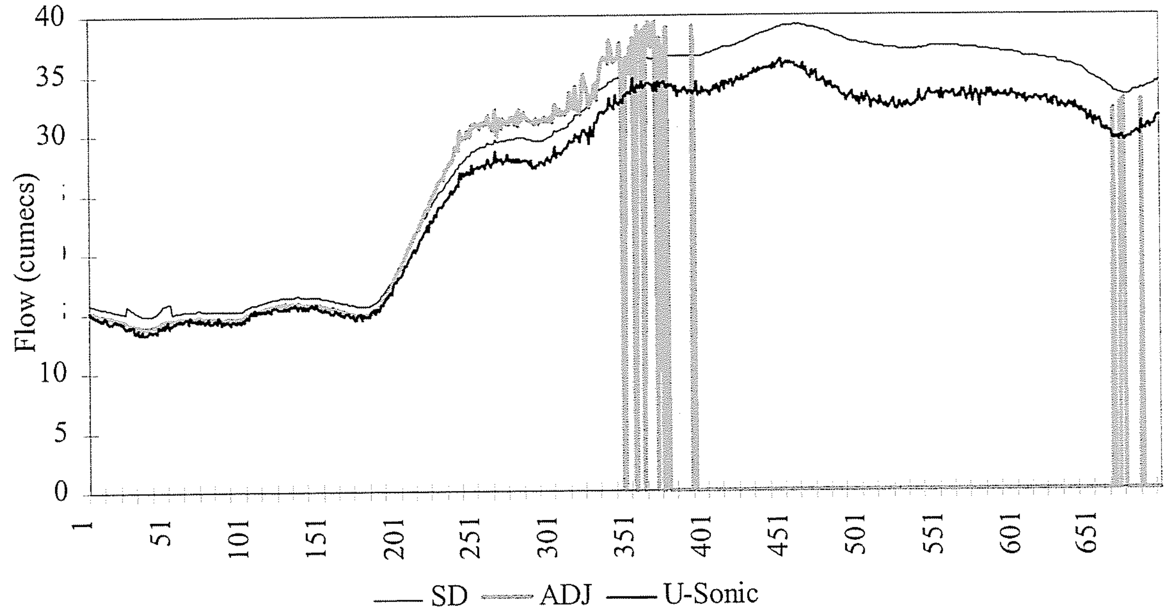


Figure 5.5 Flows at Walcot between January 1st and 8th 1998, produced by the Agency rating (SD), adjusted weir formula (ADJ) and ultrasonic gauge (U-Sonic) with the velocity paths at 0.5 and 0.8 metres above the weir invert.

The first point to be noted from Figure 5.5 is the high proportion of time that the adjusted weir formula iteration is unable to function. This is because flows were higher than those of the December 1996 event plotted in Figure 5.4. Secondly, on this occasion the flows produced by the ultrasonic gauge are closer to those of the Agency rating than in Figure 5.4. For example, the stage-discharge flow of 25 cumecs was associated with an ultrasonic gauge flow of only 20.1 cumecs in the first event, when the velocity paths were lower, compared to 23.6 cumecs in Figure 5.5. It is thought that this increase is due to two facts: the transducer paths are higher, and would thus be expected to record higher velocities, and the modular limit and/or degree of drowning may have been higher and/or lower respectively during this event.

Finally, it can be seen that on this occasion the adjusted weir formula produces higher flows for a given stage than both the ultrasonic gauge and the Agency rating. Whilst it is possible that the flows are significantly higher for a given stage during the second event, it is considered unlikely that the increase will be as much as that shown in Figure 5.5. To enable this to be discussed further, Figure 5.6 shows the stage-discharge ratings produced from both events by all three methods.

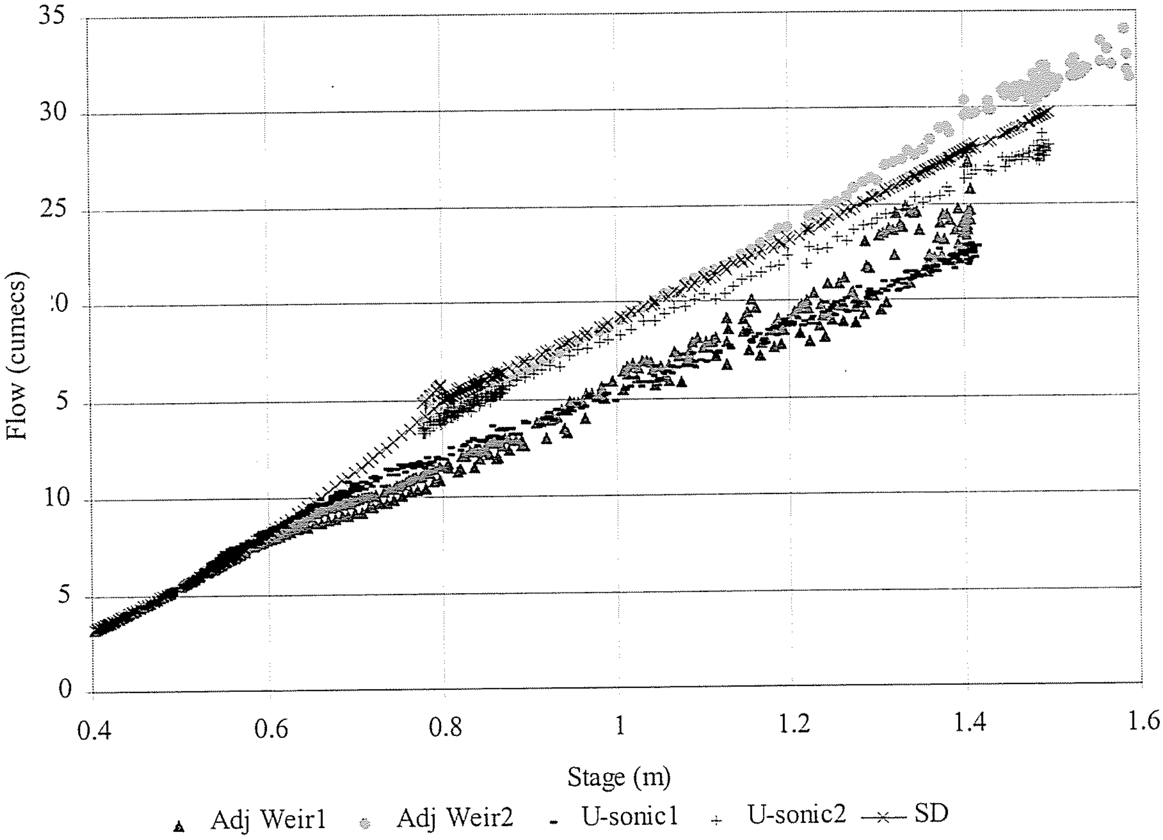


Figure 5.6 Stage-discharge ratings for Walcot derived from the adjusted weir formula in December 1996 (Adj Weir1) and January 1998 (Adj Weir2), the ultrasonic gauge in December 1996 (U-sonic1) and in January 1998 (U-sonic2), together with the Agency rating for the site.

It can be seen from Figure 5.6 that both the ultrasonic and adjusted weir flows are higher for a given stage during the second event than the first. In the case of the ultrasonic data this may be partially explained by the fact that the transducers are higher, although it is considered unlikely that this would result in flows increasing by as much as 20% (ie from 19 to 23 cumecs at a stage of 1.2 metres). It must therefore be concluded that there was a real difference in the hydraulic conditions in the channel between the two events, and that the weir was able to operate more efficiently during the second event.

The increase in channel efficiency undoubtedly accounts for at least part of the difference between the two adjusted weir relationships plotted in Figure 5.6. However, when these are compared to their respective ultrasonic gauge data sets, it can be seen that the adjusted weir formula rating from the second event consistently produces higher flows for a given stage than the ultrasonic data from the same event. This is in contrast to the first event, where the flow data follow a similar pattern to that observed in the velocity analysis described in 5.1 and plotted in Figure 5.3, ie the flows produced by the two approaches are very similar, with the ultrasonic gauge producing slightly higher values up to a stage of approximately one metre, and the adjusted weir equation producing higher values above this.

Whilst it is reasonable to assume that this relationship will also exist for the second event, it would be expected that the flows would coincide up to a higher stage than the one metre level as the transducer paths were deployed at higher levels. This is clearly not the case as the adjusted weir formula produces consistently higher flow values for a stage level of 0.7 metres and above.

It can thus be seen that whilst the ultrasonic gauge produces consistent data over the two events, it would appear that the flows produced by the adjusted weir formula are less so. Although both approaches demonstrate that the channel conditions were different for the two events, further confirming that systematic errors will arise from the use of a single stage-discharge rating, a more detailed analysis of the relationship between the flows produced by the approaches suggests that there is some uncertainty in those produced by the adjusted weir formula. This uncertainty is discussed in detail in Chapter 6 of the Technical Report, and includes the issue of well lag/and or blockage in the crest tapping system

Whilst there is no direct evidence to indicate that the Walcot crest tapping well experienced any lag during either of the two events, data collected during April 1998 indicate that the well does become blocked. This is illustrated in Figure 5.7, which shows that the crest tapping becomes completely blocked when upstream levels are at approximately 1.2 metres shortly after 0000 on 11th April. Two 'steps' can be seen in the crest tapping plot - the first shortly after 1200 on the 11th April, and the second 16 hours later, when the well appears to become operational again. It is thought that these steps may coincide with the pumping system operation.

The above example illustrates a worse case scenario, ie the tapping becomes fully blocked. Whilst this did not occur during either of the two events used for the analysis presented in Section 5.2, it does indicate that the system is prone to silting up. This is unlikely to be an instantaneous occurrence, but is more likely to take place over a period of time. This suggests that there is a possibility that the crest tapping may have been partially blocked during the second event (when the frequency of flushing was less than in December 1996), and that well levels may therefore have lagged behind the true water pressure at the crest.

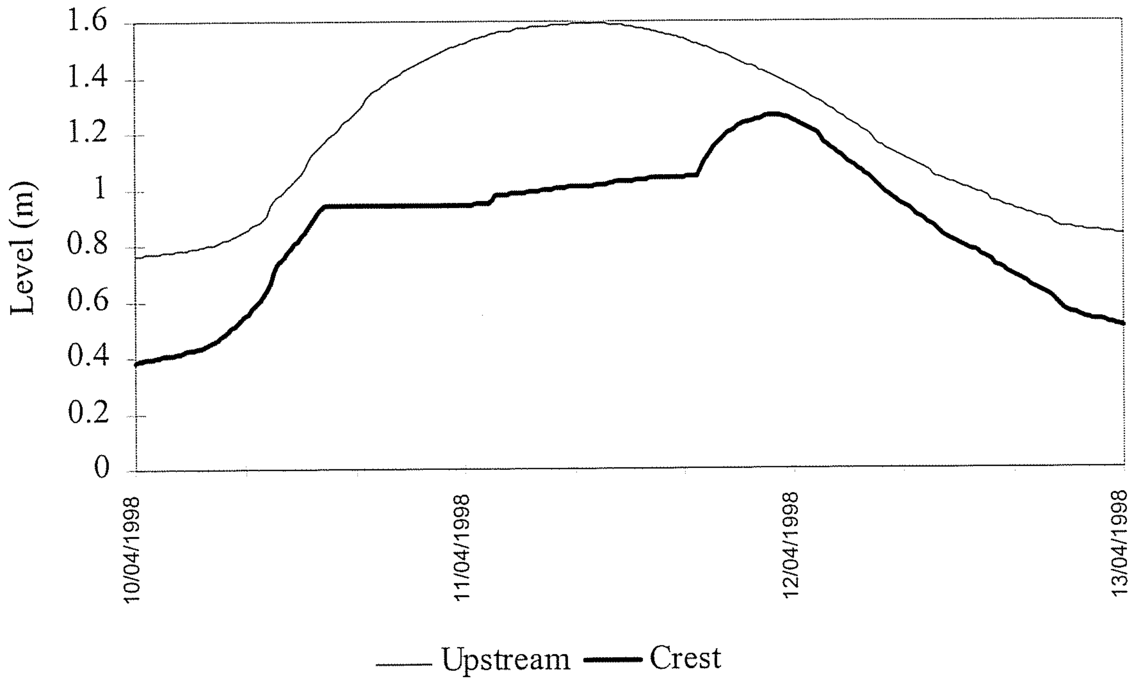


Figure 5.7 Upstream and crest tapping levels collected at Walcot between 1200 on the 10th April and 1200 on the 13th April 1998. The tick marks on the time axis are at eight hour intervals.

Further confirmation of the potential for well lag is provided by a theoretical analysis of the Walcot crest tapping system undertaken for the Agency flat V weirs R&D Project. This indicated that, even when unaffected by silt, the system may be physically incapable of filling the stilling well during a flood event. (The water to fill the 1.5 m^2 well is only able to enter the system via five holes 10 mm in diameter). During falling levels the well is able to keep up with the river.

It can thus be seen that whilst there is no hard evidence to confirm that the crest tapping stilling well encountered any lag during the January 1998 event, there is strong circumstantial evidence to suggest that this was likely. If so, this would account for the apparent 'discrepancy' in the flows from the adjusted weir equation approach, which were higher than expected. A higher crest tapping reading would have increased the reduction factor, resulting in the flows being reduced.

6 REFLECTOR STUDIES

The success of the reflector trials at Lea Hall led to the decision to undertake further trials at Walcot, where access to both banks was straightforward and it was known that the gauge performed well under all flow conditions. Trials were undertaken on 16th September 1998.

Due to the relatively low river flows only one of the transducer paths was submerged at the time the trials were undertaken. On arriving at the site the previous day it was found that this path had failed due to extensive weed growth in the channel. This was cleared, together with the weed along the anticipated line of the reflected path. An additional transducer rack was installed on the near bank, some 30 metres upstream of the weir crest, and the trials were undertaken in the following order:

- Seven sets of velocity data were collected from the original configuration at five minute intervals.
- The reflector was then installed and aligned, following which a set of six velocity readings were taken at five minute intervals.
- Finally, the transducers were returned to the original configuration and a set of six velocity readings were taken, again at five minute intervals.

The collected data are shown in Table 6.1, and plotted in Figure 6.1.

Table 6.1 Data collected from the reflector trials undertaken at Walcot on the 16th September 1998. The data are presented in order of collection, ie the first two columns of data were the first to be collected from the original configuration.

Original Configuration		Reflector Configuration		Original Configuration	
Path velocity (m/s)	Count (max 255)	Path velocity (m/s)	Count (max 255)	Path velocity (m/s)	Count (max 255)
0.260	255	0.291	122	0.256	255
0.252	255	0.266	118	0.256	255
0.258	255	0.287	19	0.263	255
0.259	255	0.271	109	0.263	255
0.257	255	0.269	113	0.257	255
0.258	255	0.264	124	0.261	255
0.260	255				
Mean values					
0.258	255	0.274	101	0.259	255

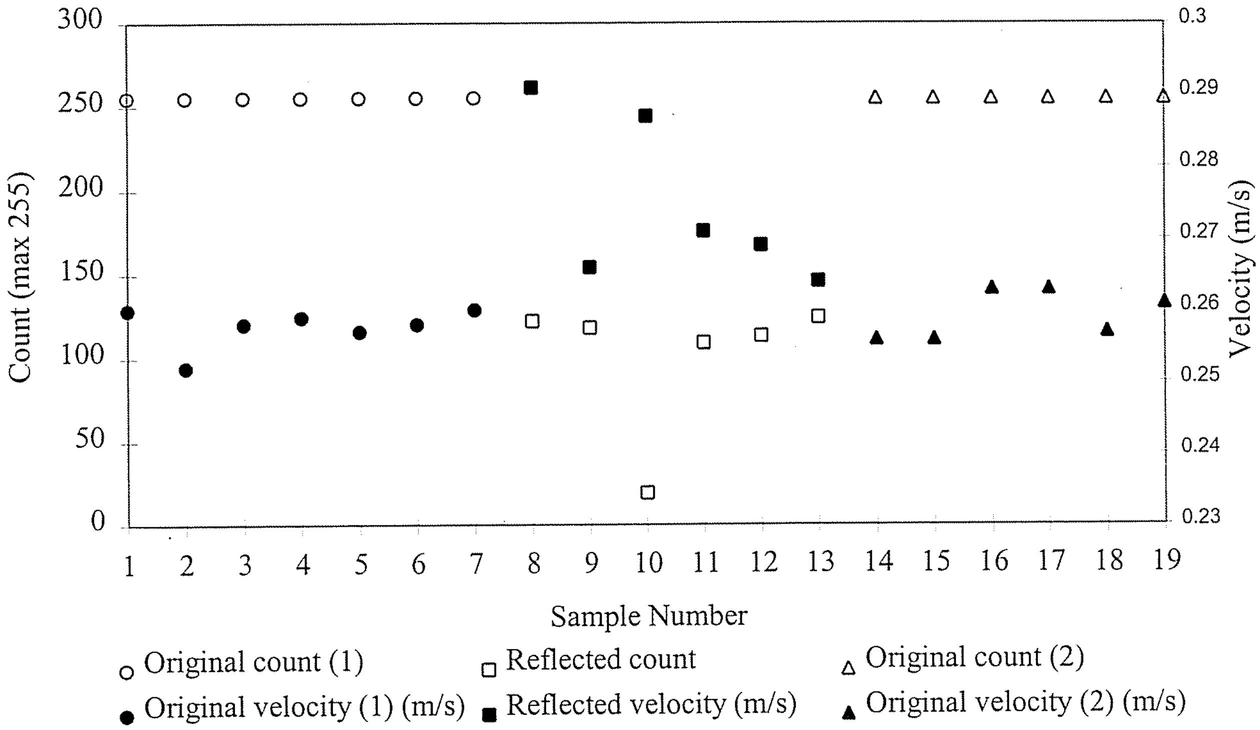


Figure 6.1 Velocity and count data for the single transducer path collected during the reflector trials at Walcot.

The first and most dramatic point to note from these data is the reduction in the count values for the reflected configuration data set. Mean count values fall from the maximum of 255 to only 101. Unlike Lea Hall, this is not due to disturbed sediment in the channel - note that the second set of velocity collected with the original configuration at the end of the study recorded maximum count values of 255. Instead, it is probable that this reduction in count is due to increased attenuation of the acoustic beam, arising from the path length increasing from 20.8 to 41 metres. Whilst it might be argued that this signal loss may also be due to increased interference from weed, great care was taken to ensure that the reflected transducer path was as clear as possible from all weed.

The second point to note is that, in direct contrast to the data collected at Lea Hall, the reflected path velocity data values are higher than those collected from the original configuration. The mean sub-set velocities increase from 0.258 to 0.274 m/s, before falling to 0.259 m/s. In both relative and absolute terms the transducer racks were much further upstream of the weir crest than at Lea Hall, resulting in negligible influence on the water velocity. However, a much more significant factor is that the upstream channel is significantly shallower than that close to the weir - typically 0.5 metres compared to almost twice this. It can thus be seen that even when pooling and 'dead zone' influences are considered, the velocity along the upstream reflected path will be much higher than that along the transducer path used by the original configuration. The actual difference, based on mean path velocities of 0.258 and 0.274 m/s, is of the order of 0.03 m/s (ie twice the difference of the two values), or 12% of the original configuration mean path velocity.

It can thus be seen that the studies at Walcot serve to confirm and build on the findings at Lea Hall. Whilst the gauge is able to work with a reflected velocity path, the amount of the acoustic signal that is successfully detected is greatly reduced. Typical count values were more than halved for a channel that is between 15 and 20 metres wide. If it is remembered that this was under low flow conditions, when sediment loads were low, it can be seen that the probability of gauge failure during high flows and associated higher sediment loads will be increased. However, should it be absolutely necessary to use a reflector system, the Walcot studies have further confirmed that the equipment is sensitive enough to detect subtle changes in the channel velocities as channel geometry changes.

7 SUMMARY

The results from the Walcot field trials presented in this Site Report have demonstrated that the twin path ultrasonic gauge is able to establish stage-velocity relationships for an open channel section at what is known to be a 'difficult' site. Comparison with data collected from one of the few operational crest tapping systems in the UK have confirmed that the gauge is able to produce velocity data that reflect the changing hydraulic conditions within a channel, both during an event and for a number of different events. Furthermore, the results collected at Walcot suggests that the gauge offers a means of not only establishing whether or not non-modular conditions occur at a site, but may also identify the modular limit, albeit on a relatively coarse basis.

The Walcot results have also shown that the gauge is able to determine flows under changing hydraulic conditions. Because of uncertainties in the establishment of the 'true' flow at the site it has not been possible to undertake a thorough assessment of gauge performance, or to extend the analysis of the significance of the 'mean bed level' or 'bed correction factor' parameters. Despite this, the 'default' flows produced by the gauge follow a pattern that is consistent with other field sites. During low flows the gauge tends to over-estimate the true flow, whilst peak flows are under-estimated. The degree of over/underestimation depends on the height at which the paths are deployed, and the values of the gauge parameters.

The reflector studies undertaken at Walcot have further confirmed the findings of the Lea Hall studies. In addition to demonstrating that reflector systems can work, if they have to be used, the studies have shown that this is accompanied by a decrease in signal strength, and consequently gauge integrity, due to the increase in signal attenuation.

Finally, the gauge appears to offer a viable alternative to established methods of measuring flows at sites which are known to experience non-modular conditions, be they variable or fixed. In terms of capital investment the gauge costs less than the crest tapping flushing system (current cost approximately £11,000), which to date has proved to be the only other suitable means of correcting for non-modular flows at flat V weir sites. Operational costs will also be similar, and whilst both approaches have their deficiencies and limitations, there is no evidence to suggest that either method is superior to the other. Certainly, the ultrasonic gauge is the only approach that can be retrospectively installed at a site that does not have an existing crest tapping.

15 RAR OUTPUT FROM AGENCY MULTIPATH GAUGES

All data supplied by Midlands Region of the Environment Agency

Date are listed as one-minute velocity readings for each velocity path, in m/s.

All levels are relative to stage datum, and are expressed in metres.

Velocity path and bed levels for each gauge are as follows:

Path No	Saxons Lode	Buildwas	Montford	Deerhurst
1	-2.40	-0.932	-0.62	-2.16
2	-2.39	-0.930	-0.62	-2.16
3	-1.80	-0.632	-0.22	-1.66
4	-1.79	-0.630	-0.22	-1.66
5	-1.20	-0.312	0.18	-1.16
6	-1.19	-0.310	0.18	-1.16
7	-0.66	-0.032	0.58	-0.66
8	-0.59	-0.030	0.58	-0.66
9	0.00	0.270	1.18	-0.16
10	0.01	0.272	1.18	-0.16
11	0.60	1.070	1.88	0.34
12	0.61	1.072	1.88	0.34
13	1.80	2.250	2.40	1.34
14	1.81	2.252	2.40	1.34
15	3.00	3.500	3.30	2.84
16	3.01	3.502	3.30	2.84
17		4.400	4.30	4.34
18		4.402	4.30	4.34
19		5.550		
20		5.552		
Mean bed level	-3.348	-1.875	-1.649	-2.642

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                                                                   Void            Header
 62/10     .806    .818    .807    .815    .814    .82     .828    .825    .825    62.10
                                                                   Void            Header
 62/11     .796    .775    .76     .803    .791    .776    .765    .781    .781    62.11
                                                                   Void            Header
 62/12     .819    .822    .803    .807    .814    .823    .823    .835    .835    62.12
                                                                   Void            Header
 62/13     .75     .733    .72     .782    .743    .755    .761    .755    .755    62.13
                                                                   Void            Header
 62/14     .808    .788    .747    .74     .762    .755    .745    .793    .793    - - -
                                                                   Void
***/15     - - -   - - -   - - -   - - -   - - -   - - -   - - -   62.15   62.15   01.00
                                                                   Void    Header  Header
  1/ 0     19512   19327   18965   19809   19640   19287   19342   62.16   62.16   - - -
                                                                   Void    Header
***/17     - - -   - - -   - - -   - - -   - - -   - - -   - - -   1       1       02.00
                                                                   Void    Fatal   Header
  2/ 0     2.356   2.352   2.35    2.35    2.348   2.35    2.345   62.18   62.18   - - -
                                                                   Void    Header
***/19     - - -   - - -   - - -   - - -   - - -   - - -   - - -   999999  999999  - - -
                                                                   Void    Fatal
***/20     - - -   - - -   - - -   - - -   - - -   - - -   - - -   999999  999999  - - -
                                                                   Void    Fatal
 Live Data                                                  09:40 on 19Feb97
```

SAXONS LODE

Func/Pth	9:53	9:52	9:51	9:50	9:49	9:48	9:47	9:46	9:45	9:44
62/ 1	.774	.79	.772	.755	.792	.79	.768	.774	.784	.748
62/ 2	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	-99999 Fatal	1 Fatal
62/ 3	.777	.788	.792	.759	.79	.797	.778	.775	.794	.746
62/ 4	.843	.818	.805	.861	.848	.828	.842	.844	.861	.847
62/ 5	.811	.818	.831	.797	.819	.831	.81	.806	.827	.777
62/ 6	.846	.813	.808	.84	.85	.813	.837	.832	.866	.832
62/ 7	.832	.828	.852	.829	.837	.855	.84	.821	.848	.803
62/ 8	.869	.832	.814	.865	.864	.835	.856	.852	.871	.851
62/ 9	.843	.836	.861	.85	.85	.867	.864	.826	.857	.825
62/10	.927	.892	.878	.923	.916	.897	.917	.902	.917	.909
62/11	.837	.833	.854	.85	.844	.865	.861	.822	.849	.823
62/12	.876	.844	.838	.854	.853	.85	.861	.847	.862	.854
62/13	.766	.784	.784	.789	.778	.792	.802	.775	.778	.763
62/14	.85	.848	.827	.83	.853	.827	.843	.828	.841	.864
62/15	.669	.684	.68	.678	.672	.682	.699	.668	.668	.658
62/16	1 Fatal	1 Fatal	1 Fatal	1 Fatal	999.99 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal
62/17	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal	1 Fatal
2/ 0	3.46	3.461	3.461	3.461	3.462	3.461	3.461	3.461	3.451	3.464
***/19	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
1/ 0	25520	25467	25329	25414	25646	25609	25752	25244	25630	25080

Live Data

09:53 on 26Feb97

Tony

Higher flows than previously sent

Richard

```
         Hdg:2================= SAXONS LODE ==========================================================
Func/Pth  14:05  | 14:04  | 14:03  | 14:03  | 14:02  | 14:02  | 14:01  | 14:00  | 13:59  | 13:58
 62/ 1    1        1        1        1        1        1        1        1        1        1
          Fatal    Fatal    Fatal    Fatal    Void     Fatal    Fatal    Fatal    Fatal    Fatal
 62/ 2    .898     .901     .904     .874     .874     .887     .885     .886     .888     .891
                                              Void
 62/ 3    .708     .711     .732     .74      .74      .721     .737     .718     .724     .737
                                              Void
 62/ 4    .735     .759     .727     .739     .739     .73      .733     .757     .776     .763
                            Fatal             Void
 62/ 5    .752     .755     .753     .774     .774     .744     .771     .742     .741     .756
          Fatal                      Fatal    Void     Fatal
 62/ 6    .758     .791     .777     .775     .775     .8       .752     .778     .779     .8
          Fatal    Fatal    Fatal    Fatal    Void     Fatal             Fatal
 62/ 7    .765     .757     .768     .776     .776     .767     .774     .757     .761     .769
                                              Void
 62/ 8    .805     .842     .821     .798     .798     .822     .793     .802     .837     .822
                                              Void
 62/ 9    ????     .763     .765     .771     .771     .771     .777     .762     .768     .773
                                              Void
 62/10    ????     .827     .827     .8       .8       .816     .8       .815     .829     .821
                                              Void
 62/11    ????     .744     .745     .754     .754     .755     .766     .745     .754     .755
                                              Void
 62/12    ????     .799     .807     .772     .772     .791     .786     .788     .813     .796
                                              Void
 62/13    ????     1        1        1        1        1        1        1        1        1
                   Fatal    Fatal    Fatal    Void     Fatal    Fatal    Fatal    Fatal    Fatal
***/14    - - -    - - -    - - -    - - -    23       - - -    - - -    - - -    - - -    - - -
                                              Void
  1/ 0    ????     19348    19401    18988    18988    19180    19183    19087    19385    19408
                                              Void
***/16    - - -    - - -    - - -    - - -    23       - - -    - - -    - - -    - - -    - - -
                                              Void
  2/ 0    ????     2.105    2.106    2.105    2.105    2.104    2.112    2.104    2.087    2.115
                                              Void
***/18    - - -    - - -    - - -    - - -    23       - - -    - - -    - - -    - - -    - - -
                                              Void
***/ 0    - - -    - - -    - - -    - - -    23       - - -    - - -    - - -    - - -    - - -
                                              Void
***/ 0    - - -    - - -    - - -    - - -    23       - - -    - - -    - - -    - - -    - - -
                                              Void
======== Live Data=========================================================14:06 on 05Dec96=======
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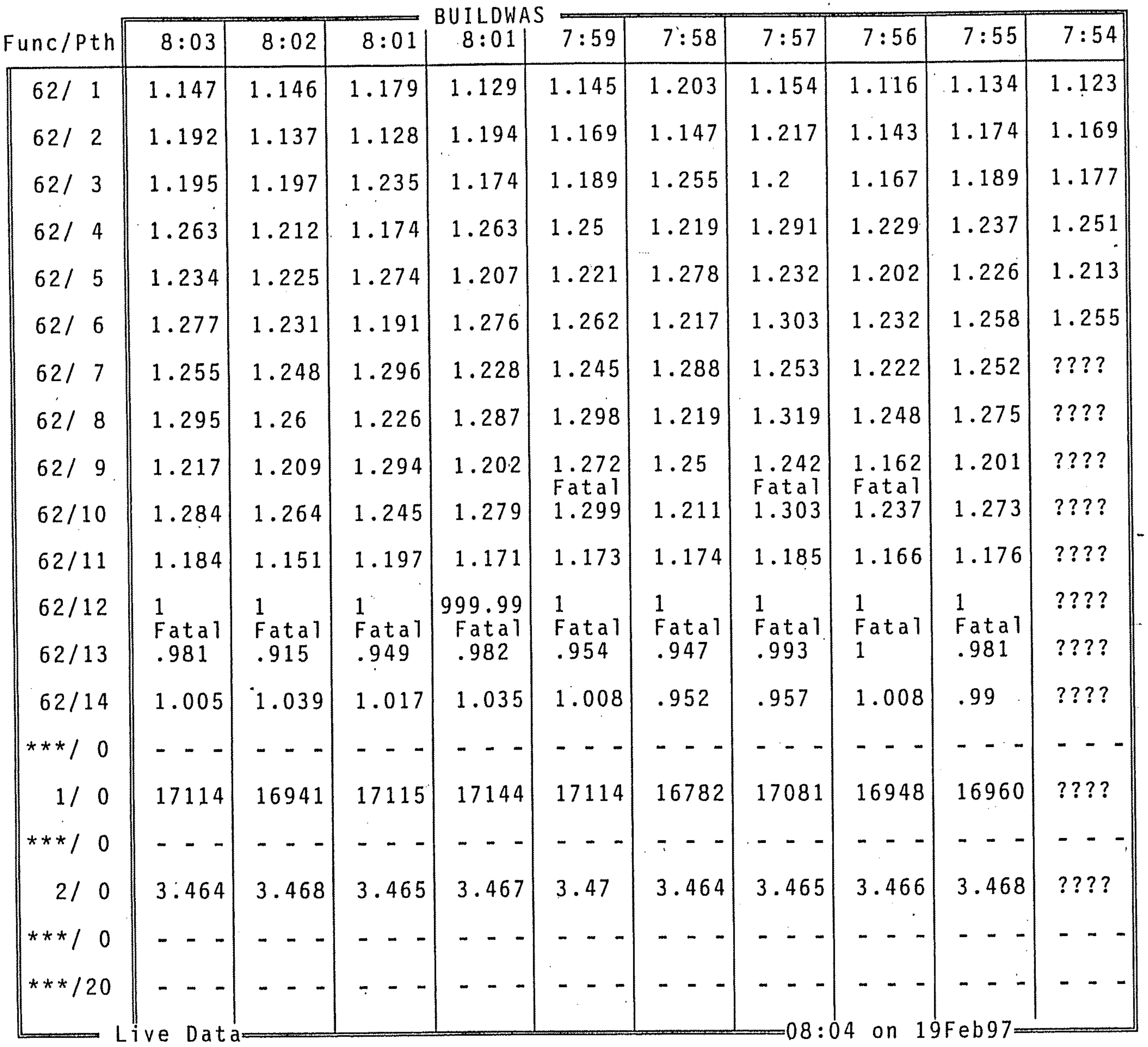
         èëëëëëëîëëëëëëîëëëëëë BUILDWAS ëëëëîëëëëëëîëëëëëëîëëëëëëîëëëëëëîëëëëëë
Func/Pth¤  9:05°  9:04°  9:03°  9:02°  9:01°  9:00°  8:59°  8:58°  8:57°  8:56
øáááááááæááááááéááááááéááááááéááááááéááááááéááááááéááááááéááááááéááááááéáááááá
¤ 62/ 1 ¤ 1.136° 1.088° 1.109° 1.098° 1.115° 1.114° 1.098° 1.094° 1.122° 1.092
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 2 ¤ 1.106° 1.152° 1.134° 1.156° 1.144° 1.17 ° 1.134° 1.159° 1.121° 1.147
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 3 ¤ 1.179° 1.138° 1.154° 1.139° 1.16 ° 1.16 ° 1.142° 1.134° 1.164° 1.126
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 4 ¤ 1.17 ° 1.21 ° 1.184° 1.224° 1.198° 1.223° 1.193° 1.213° 1.181° 1.219
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 5 ¤ 1.207° 1.155° 1.175° 1.174° 1.188° 1.19 ° 1.168° 1.158° 1.185° 1.143
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 6 ¤ 1.183° 1.213° 1.198° 1.237° 1.217° 1.255° 1.201° 1.226° 1.2  ° 1.214
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 7 ¤ 1.228° 1.166° 1.179° 1.201° 1.203° 1.21 ° 1.198° 1.177° 1.199° 1.165
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 8 ¤ 1.188° 1.225° 1.214° 1.252° 1.235° 1.275° 1.213° 1.238° 1.214° 1.222
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 9 ¤ 1.177° 1.103° 1.124° 1.145° 1.135° 1.155° 1.149° 1.124° 1.141° 1.1
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/10 ¤999.99°999.99°999.99° 1.236° 1.245° 1.253° 1.166°999.99°999.99°999.99
¤       ¤ Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal
¤ 62/11 ¤ 1.136° 1.072° 1.07 ° 1.115° 1.075° 1.104° 1.137° 1.086° 1.084° 1.092
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/12 ¤999.99°999.99°999.99° 1.13 ° 1.08 ° 1    ° 1    °999.99°999.99°999.99
¤       ¤ Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal
¤ 62/13 ¤ .943 ° .924 ° .928 ° .922 ° .885 ° .892 ° .926 ° .928 ° .935 ° .926
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/14 ¤ .879 ° .948 ° .926 ° .884 ° .917 ° .923 ° .866 ° .944 ° .95  ° .968
¤       ¤      o      o      o      o      o      o      o      o      o
¤***/15 ¤ - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -
¤       ¤      o      o      o      o      o      o      o      o      o
¤  1/ 0 ¤ 15477° 15321° 15301° 15331° 15267° 15468° 15287° 15421° 15520° 15456
¤       ¤      o      o      o      o      o      o      o      o      o
¤***/17 ¤ - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -
¤       ¤      o      o      o      o      o      o      o      o      o
¤  4/ 0 ¤ 15374° 15362° 15358° 15361° 15363° 15374° 15369° 15380° 15368° 15365
¤       ¤      o      o      o      o      o      o      o      o      o
¤***/ 0 ¤ - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -
¤       ¤      o      o      o      o      o      o      o      o      o
¤  2/ 0 ¤ 3.315° 3.317° 3.316° 3.317° 3.317° 3.317° 3.317° 3.318° 3.32 ° 3.317
¤       ¤      o      o      o      o      o      o      o      o      o
àëëëëë Live Dataëëëëëëüëëëëëëüëëëëëëüëëëëëëüëëëëëëüëëë09:06 on 05Dec96ëëëëëëë
```



```
                                  BUILDWAS
Func/Pth   8:03    8:02    8:01    8:01    7:59    7:58    7:57    7:56    7:55    7:54

  62/ 1    1.147   1.146   1.179   1.129   1.145   1.203   1.154   1.116   1.134   1.123
  62/ 2    1.192   1.137   1.128   1.194   1.169   1.147   1.217   1.143   1.174   1.169
  62/ 3    1.195   1.197   1.235   1.174   1.189   1.255   1.2     1.167   1.189   1.177
  62/ 4    1.263   1.212   1.174   1.263   1.25    1.219   1.291   1.229   1.237   1.251
  62/ 5    1.234   1.225   1.274   1.207   1.221   1.278   1.232   1.202   1.226   1.213
  62/ 6    1.277   1.231   1.191   1.276   1.262   1.217   1.303   1.232   1.258   1.255
  62/ 7    1.255   1.248   1.296   1.228   1.245   1.288   1.253   1.222   1.252   ????
  62/ 8    1.295   1.26    1.226   1.287   1.298   1.219   1.319   1.248   1.275   ????
  62/ 9    1.217   1.209   1.294   1.202   1.272   1.25    1.242   1.162   1.201   ????
                                           Fatal           Fatal   Fatal
  62/10    1.284   1.264   1.245   1.279   1.299   1.211   1.303   1.237   1.273   ????
  62/11    1.184   1.151   1.197   1.171   1.173   1.174   1.185   1.166   1.176   ????
  62/12    1       1       1       999.99  1       1       1       1       1       ????
           Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal
  62/13    .981    .915    .949    .982    .954    .947    .993    1       .981    ????
  62/14    1.005   1.039   1.017   1.035   1.008   .952    .957    1.008   .99     ????
 ***/ 0    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
   1/ 0    17114   16941   17115   17144   17114   16782   17081   16948   16960   ????
 ***/ 0    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
   2/ 0    3.464   3.468   3.465   3.467   3.47    3.464   3.465   3.466   3.468   ????
 ***/ 0    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
 ***/20    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
   Live Data                                         08:04 on 19Feb97
```

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         èHdg:1ëîëëëëëëîëëëëëë BUILDWAS ëëëëîëëëëëëîëëëëëëîëëëëëëîëëëëëëîëëëëëë
Func/Pth¤  8:18°  8:17°  8:16°  8:15°  8:14°  8:13°  8:12°  8:11°  8:10°  8:09
øáááááááæááááááéááááááéááááááéááááááéááááááéááááááéááááááéááááááéááááááéáááááá
¤ 62/ 1 ¤ .922 ° .855 ° .873 ° .902 ° .911 ° .877 ° .885 ° .891 ° .892 ° .86
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 2 ¤ .798 ° .815 ° .852 ° .77  ° .833 ° .816 ° .804 ° .796 ° .792 ° .824
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 3 ¤ .964 ° .894 ° .919 ° .952 ° .952 ° .927 ° .919 ° .932 ° .932 ° .897
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 4 ¤ .841 ° .853 ° .894 ° .807 ° .866 ° .86  ° .841 ° .834 ° .824 ° .853
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 5 ¤ .985 ° .924 ° .943 ° .977 ° .968 ° .962 ° .939 ° .967 ° .953 ° .92
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 6 ¤ .865 ° .878 ° .909 ° .824 ° .874 ° .878 ° .864 ° .854 ° .842 ° .86
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 7 ¤ .979 ° .932 ° .947 ° .976 ° .971 ° .983 ° .946 ° .98  ° .963 ° .932
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 8 ¤ .876 ° .888 ° .906 ° .828 ° .882 ° .886 ° .872 ° .857 ° .857 ° .859
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 9 ¤ .899 ° .877 ° .885 ° .904 ° .906 ° .919 ° .886 ° .917 ° .897 ° .901
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/10 ¤ 1    ° 1    ° .873 ° .818 ° .811 ° .797 ° .733 ° .833 ° 1    °999.99
¤       ¤ Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal° Fatal
¤ 62/11 ¤ .787 ° .824 ° .813 ° .797 ° .813 ° .836 ° .821 ° .832 ° .807 ° .825
¤       ¤      o      o      o      o      o      o      o      o      o
¤***/ 0 ¤ - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -
¤       ¤      o      o      o      o      o      o      o      o      o
¤  1/ 0 ¤ 8549 ° 8379 ° 8503 ° 8541 ° 8672 ° 8610 ° 8281 ° 8872 ° 8716 ° 8815
¤       ¤      o      o      o      o      o      o      o      o      o
¤  4/ 0 ¤ 8597 ° 8615 ° 8622 ° 8622 ° 8648 ° 8647 ° 8669 ° 8686 ° 8646 ° 8647
¤       ¤      o      o      o      o      o      o      o      o      o
¤  8/ 0 ¤ 10168° 10168° 10168° 10168° 10168° 10168° 10168° 10168° 10168° 10168
¤       ¤      o      o      o      o      o      o      o      o      o
¤***/ 0 ¤ - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -
¤       ¤      o      o      o      o      o      o      o      o      o
¤  2/ 0 ¤ 2.097° 2.097° 2.097° 2.098° 2.098° 2.1  ° 2.099° 2.104° 2.105° 2.106
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 11/ 0 ¤ 2.089° 2.089° 2.092° 2.092° 2.092° 2.092° 2.092° 2.092° 2.092° 2.092
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 22/ 0 ¤ 2.096° 2.097° 2.097° 2.096° 2.098° 2.1  ° 2.098° 2.103° 2.103° 2.105
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 42/ 0 ¤ 2.098° 2.098° 2.098° 2.099° 2.099° 2.1  ° 2.099° 2.105° 2.106° 2.107
¤       ¤      o      o      o      o      o      o      o      o      o
àëëëëë Live Dataëëëëëëüëëëëëëüëëëëëëüëëëëëëüëëëëëëüëëë08:18 on 02Dec96ëëëëëëëë
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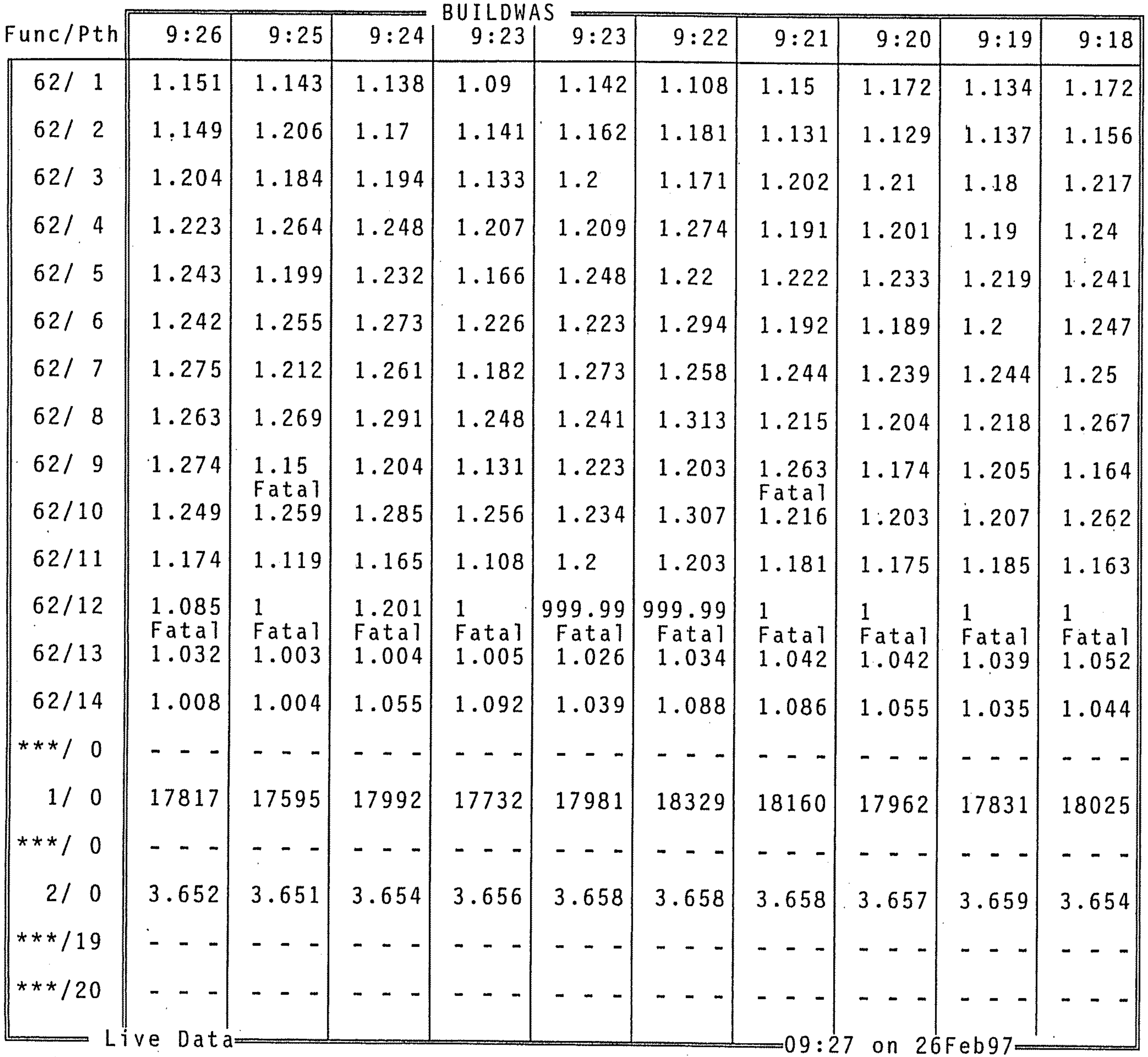
                               BUILDWAS
Func/Pth   9:11    9:10    9:09    9:08    9:07    9:06    9:05    9:04    9:03    9:03

 62/ 1    1.115   1.119   1.184   1.131   1.146   1.128   1.107   1.138   1.128   1.122
 62/ 2    1.174   1.176   1.131   1.251   1.192   1.177   1.169   1.19    1.229   1.136
 62/ 3    1.168   1.161   1.23    1.175   1.191   1.174   1.165   1.186   1.168   1.181
 62/ 4    1.248   1.232   1.214   1.306   1.261   1.224   1.239   1.259   1.311   1.214
 62/ 5    1.198   1.191   1.257   1.201   1.217   1.21    1.204   1.224   1.199   1.215
 62/ 6    1.281   1.238   1.232   1.304   1.28    1.246   1.259   1.274   1.305   1.208
 62/ 7    1.221   1.21    1.274   1.226   1.238   1.24    1.218   1.255   1.224   1.242
 62/ 8    1.311   1.254   1.26    1.317   1.307   1.259   1.279   1.292   1.319   1.234
 62/ 9    1.167   1.141   1.202   1.201   1.175   1.185   1.226   1.22    1.207   999.99
                  Fatal                                                          Fatal
 62/10    1.307   1.248   1.255   1.301   1.31    1.26    1.271   1.291   1.303   1.236
 62/11    1.164   1.131   1.14    1.171   1.144   1.155   1.153   1.168   1.143   1.119
 62/12    1.239   1.167   1.151   1       1       1.078   1.158   1       1       999.99
          Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal
 62/13    1.015   1.013   .971    1.014   .99     .985    .969    .991    1.014   .952
 62/14    1.049   1.069   1.026   1.027   1.024   1.044   1.058   1.089   1.076   1.082
***/ 0    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
  1/ 0    ????    ????    ????    ????    ????    ????    ????    ????    ????    - - -
***/ 0    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   62.17   1
                                                                         Header  Fatal
  2/ 0    3.655   3.656   3.657   3.657   3.657   3.659   3.658   3.66    3.659   3.658
***/19    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   62.19   1
                                                                         Header  Fatal
***/20    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   62.20   1
                                                                         Header  Fatal
 Stored Data                                              26Feb97 at 09:11
```

BUILDWAS

Func/Pth	~~9:19~~	~~9:18~~	9:17	9:16	9:15	9:14	9:14	9:12	~~9:11~~	~~9:10~~
62/ 1	1.134	1.172	1.068	1.133	1.15	1.132	1.138	1.156	1.115	1.119
62/ 2	1.137	1.156	1.15	1.167	1.104	1.175	1.184	1.143	1.174	1.176
62/ 3	1.18	1.217	1.133	1.183	1.19	1.185	1.183	1.203	1.168	1.161
62/ 4	1.19	1.24	1.223	1.242	1.193	1.25	1.251	1.208	1.248	1.232
62/ 5	1.219	1.241	1.185	1.221	1.217	1.23	1.212	1.229	1.198	1.191
62/ 6	1.2	1.247	1.254	1.273	1.194	1.243	1.271	1.22	1.281	1.238
62/ 7	1.244	1.25	1.212	1.258	1.236	1.267	1.233	1.246	1.221	1.21
62/ 8	1.218	1.267	1.287	1.304	1.216	1.258	1.289	1.235	1.311	1.254
62/ 9	1.205	1.164	1.12	1.171	1.207	1.24	1.226	1.25 Fatal	1.167	1.141 Fatal
62/10	1.207	1.262	1.298	1.304	1.209	1.255	1.277	1.229	1.307	1.248
62/11	1.185	1.163	1.111	1.165	1.155	1.207	1.149	1.189	1.164	1.131
62/12	1 Fatal	1 Fatal	1 Fatal	1.178 Fatal	1 Fatal	1.098 Fatal	999.99 Fatal	1 Fatal	1.239 Fatal	1.167 Fatal
62/13	1.039	1.052	.986	.975	1.014	1.03	1.025	1.064	1.015	1.013
62/14	1.035	1.044	1.055	1.116	1.035	1.029	1.04	1.049	1.049	1.069
***/ 0	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
1/ 0	????	????	????	????	????	????	????	????	????	????
***/ 0	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
2/ 0	3.659	3.654	3.654	3.656	3.656	3.654	3.655	3.654	3.655	3.656
***/19	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
***/20	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -

Stored Data 26Feb97 at 09:19



```
                                  BUILDWAS
Func/Pth   9:26    9:25    9:24    9:23    9:23    9:22    9:21    9:20    9:19    9:18

  62/ 1    1.151   1.143   1.138   1.09    1.142   1.108   1.15    1.172   1.134   1.172
  62/ 2    1.149   1.206   1.17    1.141   1.162   1.181   1.131   1.129   1.137   1.156
  62/ 3    1.204   1.184   1.194   1.133   1.2     1.171   1.202   1.21    1.18    1.217
  62/ 4    1.223   1.264   1.248   1.207   1.209   1.274   1.191   1.201   1.19    1.24
  62/ 5    1.243   1.199   1.232   1.166   1.248   1.22    1.222   1.233   1.219   1.241
  62/ 6    1.242   1.255   1.273   1.226   1.223   1.294   1.192   1.189   1.2     1.247
  62/ 7    1.275   1.212   1.261   1.182   1.273   1.258   1.244   1.239   1.244   1.25
  62/ 8    1.263   1.269   1.291   1.248   1.241   1.313   1.215   1.204   1.218   1.267
  62/ 9    1.274   1.15    1.204   1.131   1.223   1.203   1.263   1.174   1.205   1.164
                   Fatal                                   Fatal
  62/10    1.249   1.259   1.285   1.256   1.234   1.307   1.216   1.203   1.207   1.262
  62/11    1.174   1.119   1.165   1.108   1.2     1.203   1.181   1.175   1.185   1.163
  62/12    1.085   1       1.201   1       999.99  999.99  1       1       1       1
           Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal   Fatal
  62/13    1.032   1.003   1.004   1.005   1.026   1.034   1.042   1.042   1.039   1.052
  62/14    1.008   1.004   1.055   1.092   1.039   1.088   1.086   1.055   1.035   1.044
 ***/ 0    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
   1/ 0    17817   17595   17992   17732   17981   18329   18160   17962   17831   18025
 ***/ 0    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
   2/ 0    3.652   3.651   3.654   3.656   3.658   3.658   3.658   3.657   3.659   3.654
 ***/19    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
 ***/20    - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -   - - -
    Live Data                                       09:27 on 26Feb97
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       èëëëëëëîëëëëëëîëëëëëë MONTFORD ëëëîëëëëëëîëëëëëëîëëëëëëîëëëëëëîëëëëëë
Func/Pth¤  8:59°  8:58°  8:57°  8:56°  8:55°  8:54°  8:54°  8:53°  8:52°  8:51
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¤ 62/ 1 ¤ 1.005° 1.02 ° .971 ° 1.024° 1.034° .997 ° 1.003° .96  ° .999 ° 1.019
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 2 ¤ .975 ° .955 ° .951 ° .965 ° .993 ° .982 ° .932 ° .938 ° .998 ° .94
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 3 ¤ 1.056° 1.071° 1.019° 1.079° 1.082° 1.045° 1.056° 1.014° 1.051° 1.075
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 4 ¤ 1.053° 1.048° 1.048° 1.048° 1.065° 1.053° 1.018° 1.024° 1.074° 1.023
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 5 ¤ 1.082° 1.112° 1.066° 1.117° 1.108° 1.093° 1.095° 1.067° 1.086° 1.125
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 6 ¤ 1.101° 1.11 ° 1.109° 1.099° 1.11 ° 1.099° 1.057° 1.085° 1.133° 1.072
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 7 ¤ 1.075° 1.106° 1.074° 1.095° 1.1  ° 1.094° 1.101° 1.069° 1.084° 1.12
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 8 ¤ 1.103° 1.112° 1.108° 1.108° 1.112° 1.093° 1.066° 1.089° 1.134° 1.08
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/ 9 ¤ 1.037° 1.061° 1.041° 1.042° 1.055° 1.061° 1.075° 1.04 ° 1.054° 1.066
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/10 ¤ 1.084° 1.1  ° 1.086° 1.091° 1.084° 1.069° 1.058° 1.078° 1.112° 1.08
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/11 ¤ .994 ° .992 ° 1.017° .998 ° 1.008° 1.002° 1.027° .996 ° 1.01 ° .999
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/12 ¤ 1.048° 1.074° 1.043° 1.056° 1.037° 1.035° 1.05 ° 1.075° 1.065° 1.059
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/13 ¤ .977 ° .957 ° 1.013° .985 ° .987 ° .977 ° .995 ° .969 ° .99  ° .975
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/14 ¤ .991 ° 1.026° .989 ° 1.001° .985 ° .993 ° 1.005° 1.038° 1.001° 1.003
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/15 ¤ .92  ° .885 ° .943 ° .935 ° .902 ° .913 ° .91  ° .909 ° .918 ° .918
¤       ¤      o      o      o      o      o      o      o      o      o
¤ 62/16 ¤ .922 ° .947 ° .919 ° .917 ° .936 ° .931 ° .963 ° .973 ° .921 ° .914
¤       ¤      o      o      o      o      o      o      o      o      o
¤  1/ 0 ¤ 13288° 13431° 13278° 13377° 13410° 13301° 13399° 13347° 13397° 13309
¤       ¤      o      o      o      o      o      o      o      o      o
¤  4/ 0 ¤ 13360° 13366° 13369° 13367° 13370° 13372° 13380° 13380° 13388° 13384
¤       ¤      o      o      o      o      o      o      o      o      o
¤  2/ 0 ¤ 4.421° 4.418° 4.421° 4.42 ° 4.418° 4.42 ° 4.418° 4.417° 4.42 ° 4.418
¤       ¤      o      o      o      o      o      o      o      o      o
¤***/ 1 ¤ - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° - - -° 62.20
¤       ¤      o      o      o      o      o      o      o      o      °Header
àëëëëë Live Dataëëëëëëüëëëëëëüëëëëëëüëëëëëëüëëëëëëüëëë09:00 on 04Dec96ëëëëëëë
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MONTFORD

Func/Pth	8:42	8:41	8:40	8:39	8:38	8:37	8:36	8:35	8:34	8:33
62/ 1	1.006	1.069	1.04	1.035	1.013	1.029	1.008	1.045	1.005	1.048
62/ 2	.973	1.011	.969	.974	.983	.985	.982	.97	1.016	.976
62/ 3	1.053	1.12	1.098	1.083	1.068	1.08	1.057	1.103	1.069	1.107
62/ 4	1.057	1.094	1.047	1.063	1.058	1.066	1.07	1.045	1.097	1.048
62/ 5	1.104	1.163	1.148	1.121	1.126	1.122	1.111	1.148	1.13	1.16
62/ 6	1.107	1.162	1.121	1.116	1.114	1.124	1.13	1.11	1.148	1.115
62/ 7	1.113	1.162	1.161	1.121	1.135	1.114	1.123	1.144	1.147	1.177
62/ 8	1.121	1.163	1.156	1.136	1.137	1.133	1.142	1.129	1.163	1.135
62/ 9	1.093	1.128	1.154	1.109	1.134	1.1	1.115	1.125	1.141	1.167
62/10	1.129	1.13	1.177	1.139	1.146	1.128	1.137	1.122	1.155	1.139
62/11	1.083	1.085	1.119	1.092	1.121	1.078	1.104	1.109	1.113	1.13
62/12	1.125	1.102	1.186	1.13	1.156	1.135	1.132	1.127	1.153	1.134
62/13	1.098	1.079	1.091	1.092	1.118	1.072	1.106	1.101	1.104	1.114
62/14	1.095	1.06	1.135	1.091	1.115	1.095	1.093	1.096	1.112	1.098
62/15	1.046	.983	.983	1.004	1.015	1.019	1.023	1.024	1.006	1.012
62/16	1.064	1.001	1.029	1.028	1.043	1.042	1.021	1.03	1.041	1.012
62/17	.955	.893	.885	.953	.899	.943	.94	.943	.889	.897
62/18	.927	.841	.853	.871	.874	.89	.868	.879	.873	.854
1/ 0	14993	14841	14994	14937	14965	14936	14907	15005	15003	15008
2/ 0	4.649	4.647	4.649	4.65	4.649	4.65	4.648	4.65	4.662	4.662

Live Data 08:42 on 19Feb97

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                                DEERHURST
Func/Pth  16:15  16:14  16:13  16:12  16:11  16:11  16:10  16:09  16:08  16:07
  62/ 1   .512   .515   .498   .515   .514   .507   .517   .513   .51    .501
  62/ 2   .529   .527   .516   .537   .538   .538   .533   .523   .528   .523
  62/ 3   .566   .575   .556   .575   .572   .566   .577   .572   .569   .556
  62/ 4   .561   .56    .554   .57    .564   .571   .566   .567   .56    .562
  62/ 5   .602   .61    .598   .613   .611   .601   .611   .607   .606   .593
  62/ 6   .579   .581   .577   .588   .586   .59    .588   .586   .589   .585
  62/ 7   .624   .631   .621   .632   .629   .618   .628   .632   .626   .62
  62/ 8   .596   .604   .598   .607   .605   .6     .607   .599   .612   .598
  62/ 9   .641   .645   .638   .646   .644   .634   .641   .718   .643   .641
  62/10   .616   .632   .624   .631   .633   .63    .631   .623   .638   .623
  62/11   .645   .649   .642   .65    .644   .634   .641   .656   .645   .645
  62/12   .632   .644   .638   .642   .65    .646   .642   .634   .652   .64
  62/13   .647   .65    .646   .647   .641   .636   .64    .647   .645   .642
  62/14   .65    .653   .645   .655   .658   .661   .655   .641   .664   .658
 ***/ 0   - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -
   1/ 0   17616  17749  17516  17789  17793  17730  17731  17685  17849  17662
 ***/ 2   - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -
   2/ 0   2.879  2.879  2.879  2.879  2.879  2.879  2.878  2.878  2.878  2.878
 ***/ 4   - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -
 ***/ 5   - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -  - - -
   Live Data                                  16:16 on 05Dec96
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16 AN ACCOUNT OF THE EVOLUTION OF THE ULTRASONIC GAUGE NETWORK IN MIDLANDS REGION

By J S Waters

1. Introduction

You have seen for yourselves this afternoon a typical ultrasonic river flow measurement station. I say typical because it has all the necessary components - even though it may not look like many or indeed any other installation in the world.

I am going to assume that, following that site visit, if you didn't know before it, you all now know and understand the fundamental principles of an ultrasonic flow measurement gauge.

What I hope to achieve over the next 45 minutes or so is to explain to you all how the present network of ultrasonic river flow gauges in Midlands Region came about - where we started, what with, what went wrong, and what we learned in the process. I hope also to dispel any remaining concerns that people may have about the accuracy and reliability of the method and I also hope to demonstrate that the technique has wider application than 'traditional' big rivers.

2. History

My introduction to the ultrasonic technique as a tool for river flow measurement came in 1975; the first installation in this Region was undergoing construction at Ashleworth on the River Severn near to Gloucester, when I arrived to take up the post of Hydrometric Officer for the Severn Basin, based in Malvern. Not only was it the first installation in the Region, it was also the first multi path gauge in the UK. This was the system developed by A.E.R.E. at Harwell with, I believe, funding from the Water Data Unit and assistance from the Water Research Centre.

I recall that this equipment and technique were to be the panacea, the cure-all for river flow measurement problems; it would work anywhere, under any conditions, with little field effort required for site investigation or site suitability. I said earlier I would tell you what went wrong, and boy, did Ashleworth go wrong! What Ashleworth actually told us, what we learned from this installation, were all the things to avoid when selecting a site for an ultrasonic flow gauge.

To be fair, Ashleworth was chosen because it was a difficult site. For a start, although multi path, it was single direction. Positioned as it was just downstream of a bend, the site was subject to skew flow, the magnitude of which was a function of velocity. There was no constant correction factor.

The site had a highly mobile bed therefore the cross sectional area was grossly unstable. Along with this mobile bed came very high suspended solids - pea soup - especially when the tide came in. With virtually every flood tide, all flight paths failed - which rather negated the benefit of a system which would measure reverse flow. All of this was compounded by the exceptionally low flows of 1975 and 1976 - the commissioning period.

Even the water level sensor used was a disaster - a complex arrangement of pressure bag and capacitance measurement. We didn't have shaft encoders yet, and frankly pressure transducers were not trusted. It is fair to say that many of the problems encountered could not have been anticipated, or even observed without "benefit" of ultrasonic technology. The 4 bit state of the art processor struggled to do the necessary processing.

Twenty years on, it is almost a joke, but many people sweated blood trying to make this installation work. We did achieve benefit in kind - we learned how not, and where not, to use the ultrasonic technique.

Also in 1975 we had some experience with the Krupp-Atlas "Flora" Ultrasonic Flow Meter. The UK agents made a system available to Severn Trent Water Authority, and this was installed in temporary fashion at a site on the River Tern in Shropshire. This evaluation produced little evidence on which to judge the system; the technology, of course, was very new to us and I think it is fair to say that the support from the agents was modest.

We did install the equipment at Saxons Lode, this time with the support of Krupp-Atlas engineers from Germany. However, once again practical difficulties ensued due to the temporary nature of the installation. For example, it was found that transducer alignment could not be maintained due to one of the mountings being vulnerable to damage from pleasure boat traffic. This work was taking place in 1976, and in those drought flows it was impossible to assess the system performance as current meter measurements were themselves subject to relatively wide margins of error.

One further attempt to evaluate the system was attempted by installing the equipment upstream of a crump weir with more robust transducer mountings. Vandals struck, and the test foundered. The conclusion at the time was that little had been learned about the equipment, but a great deal learned about the hazards of evaluation exercises.

In parallel with this work, through 1977 and 1978 we installed two of the Harwell single path systems on the River Soar at Kegworth and the River Avon at Bredon. We had more success at these sites; the accuracy was of course dependent on the user positioning the single ultrasonic path at 0.6D, or such position which was demonstrated to have mean velocity. This being a factor of depth, when depth changed and the path level stayed fixed, inaccuracy quickly occurred. With some perseverance however, and support from A.E.R.E. Harwell, these two gauges operated until the 80's, although much of the flow data should be treated with discretion.

A.E.R.E. Harwell were by now backing out of the market place. They had done their bit by developing and demonstrating a working system. I am unsure of the exact time table but in the late 70's Plessey took over the manufacture, supply and maintenance of the single path equipment. The market was fairly static, too slow and small for Plessey, and John Newman and others saw the potential for multi-path systems, acquired the rights and through a company known as Sarasota Engineering Co and later Redland Automation set about developing a much improved version. Our experience at Ashleworth etc had not totally destroyed our enthusiasm for the technique; additionally, the aforementioned drought of 1975 and 1976 had certainly sharpened our requirements for such equipment.

What seemed necessary was a kick start and S.T.W.A did just that. Against a fairly tight specification, a fully fledged contact was competitively bid by Sarasota, Krupp-Atlas and ORE for three multipath ultrasonic river flow gauges to be sited at Bewdley and Buildwas on the River Severn, and at Derby on the River Derwent. Bewdley and Derby already had long flow records, but both were potentially highly inaccurate at low flow. Bewdley was of course the control point which dictated how much water to release from Clywedog Reservoir, and inaccuracy in the flow data would result in either too much water released, or too little. The former was wasteful, and the latter meant we failed to comply with our statutory obligations.

These three gauges were constructed between 1982 and 1984.

In hindsight - which is easy - we over complicated the application at these sites, although it was recognised that some of the features were experimental and might not work.

At Bewdley, the right bank of the river has on it a public, well used footpath. It was thought that transducers on that bank would be vandalised. The theory of reflected paths was believed to be well understood, and so transducer arrays were constructed on the left bank, with reflectors on the right bank. The additional benefit was to remove the requirement for signal and power cables crossing the river.

At Buildwas and Derby, the cross path multipath arrays were interleaved; the theory was that path redundancy was a good thing, that crossed paths were a good thing, but that fully redundant crossed paths could not be afforded.

So what went wrong? From Day 1 Bewdley appeared to be perfect, and the early gauging confirmed performance. Only when the flow in the river fell to around 1200 Ml/d (the minimum maintained flow is 850 Ml/d) did the output from the gauge differ from current meter gauging. As the flow reduced to 850 Ml/d, the deviation or difference in the results increased.

Before a cure can be found, one must first identify the source of the problem. This literally took years. After all, the problem was only present under low flow conditions, and we enjoyed several drought free years at that time. Redland - who may have become Sarasota by now - did all the necessary electronic tests on the equipment. We for our part did numerous velocity profile gauging. Both parties I'm sure were suspicious of each others results.

To cut a very long story short, the source of the problem was finally identified as a diagonal gravel shoal some 500 metres upstream, which under low flow conditions was severely overgrown with aquatic weed. The effect was to cause the river to flow in a sort of sinusoidal fashion through the measuring reach, and this pattern appeared to be in harmony with the layout of the reflected path system. Higher flows simply drowned out the effect of the shoal, although it was ever present.

By reconstructing the lower paths of the gauge into a fully cross pathed system, with transducer arrays now on both banks, the gauge produced accurate data. Before we did the construction work, a temporary mounting arrangement was utilised through I believe 2 summers to prove the solution correct.

The gauge now works perfectly.

It would be strong language to say that the gauges at Buildwas and Derby went wrong, but problems were encountered.

The concept of interleaving the cross path configuration means that 50% of the time there are an odd number of paths operational. When you have skew flow, this sampling of velocities can have a bias for 50% of the time. Additionally, the transducer arrays at these sites had been most strongly engineered, resulting in the need for either the "heavy mob" or alternatively a diving team to assist with replacement of transducers. In the early days, transducers were not built to the present day quality, and failed far too often.

To improve performance at these sites, they were partially re engineered and reconfigured using GRP instead of steel for lightness and set up in very conventional cross path mode.

The gauges now work perfectly.

Also constructed in the early 1980's was a gauge on the R. Trent at Darlaston. Using a site underneath a major road bridge, it has the benefit of vertical steel piling on one bank to which transducer mountings could be attached. On the opposite bank, transducer mountings were cast into a set of concrete steps down into the river - allowing easy access. This was a particularly complex arrangement of flight paths; a major flood occurred in August 1987, the concrete steps were found to have no foundations, and they fell into the river. The gauge was rebuilt in 1988 with a more conventional transducer configuration and sloping transducer array.

Flow measurement in navigable rivers and particularly those that suffer from any backwater effects eg. downstream confluences, had been difficult if not impossible. Our successes using the ultrasonic technique led us to construct Saxons Lode, Shardlow and Pillings Lock in the period 1984-85.

Shardlow is very conventional. Saxons Lode is close to being very conventional, with only a slight deviation from the norm in the application/configuration of the very bottom path.

Pillings Lock was an attempt to stretch the technology again, with a conventional multipath gauge in the river, and with two water velocity measurement points in the flood plain. Problems with data loggers and other peripherals has meant that little useful data has been collected from these "velocity meters", but the advent of RAR has changed that. Fortunately few floods of any significance have occurred in the period since construction.

The need for good data on the lower Avon meant a rebuild of the gauge at Bredon in 1986. This time a fully crossed multi path system was installed to replace the old Harwell single path.

Ultrasonics was to provide the final solution to flow measurement on the River Tame at Bescot. This site was built originally as a trapezoidal flume in the mid 70's as part of a major Flood Defence Improvement Scheme on the river. The design bed level gradients were never realised, and the flume was ineffective. As a temporary measure and in great haste - until further channel improvements were carried out - the gauge was converted to electromagnetic, deliberately using a "temporary" insulation laid on the concrete flume. This was insufficiently robust; eventually it split, and air and water got in behind it, and the EM gauge became erratic. When the cost of installing a robust insulator became clear, together with the knowledge that the downstream channel improvements were not improving the flume performance, it was decided to install ultrasonics instead - a much cheaper solution. This was completed in 1988.

Like Bredon before it, Kegworth was now upgraded to a multipath gauge, but for sheer cheapness it is only single direction. The River Soar at this point is virtually canalised - it is very straight, with piling on the banks, and it is believed that single direction can be utilised at this site with confidence.

The same year, 1991, saw a different application for the technique. Previously used on fairly large, deep, often navigable watercourses, ultrasonic technology was seen as the solution to another flow measurement problem.

The Rivers Leen and Erewash - tributaries of the R Trent - had been turned into concrete culverts throughout their urban length some years ago by our Flood Defence colleagues. Flow gauges existed, but suffered from low flow insensitivity due to weed and algal growth, and high flow calibration by current meter was virtually impossible. At first an attempt was made to utilise the reflective technique which had failed us at Bewdley, by bouncing the signal off the divide walls. The concrete was not sufficiently smooth, so timber reflectors were tried, and steel, but were no great improvement. Eventually we returned to the tried and tested direct line of sight method which serves us so well elsewhere.

Another unusual problem at this time was a requirement for flow measurement on the River Poulter at Twyford Bridge. In the late 1960's a crump weir had been built at this point. Good old British Coal, mining away below ground, had caused sufficient subsidence over the local area for the weir block, wing walls and even the recorder house to sink, and to sink to such an extent that under the lowest flow condition the weir was non-modular. The cost of constructing a new weir would be quite high; utilising the wing walls, a small ultrasonic gauge - the Sarasota 1408 - was installed on a trial basis. Performance was such that it has not yet been removed, nor is it likely.

1992 saw the construction of an ultrasonic flow gauge on the R Severn at Montford. This site - an open channel rated section - suffered from a heavy weed growth on the downstream control.

The section itself was straight, uniform and relatively weed free, being quite deep even in the summer. The site was becoming more and more important for river regulation purposes thus requiring accurate real time data and so a multipath cross path gauge was built; this will only measure up to bankfull, and current meter gauging will be required for the out of bank flows.

It would seem from this that ultrasonics was only being used to improve or revive old gauging stations. A brand new site was required on the R Severn at Deerhurst, a few miles downstream of Tewkesbury - a wide, deep, navigable river. Perfect for ultrasonics, but care had to be taken to choose a reach with a stable bed, with little siltation. Deerhurst was constructed in 1994-95.

The last piece in the jigsaw to date was the installation of ultrasonics on the R Trent at North Muskham. This is another open channel site, rated by current meter, but with a weir control which is highly insensitive at low flows, and which has a navigation lock built in.

That then is a history of the development of the ultrasonic flow measurement network in Midlands Region. In the interest of brevity, it may appear to be triumph in the face of adversity. In reality the whole process has been very chicken and egg like, with the technology teaching us about the complexity of rivers through its use and occasional failure to perform.

Over the period, technological capability has raced ahead with the opportunity to use shaft encoders, data loggers, telemetry, RAR; the processor systems, changing from 4 bit to 32 bit micros have speeded up the entire process.

Throughout this learning curve, which for many is still quite steep, we have built on our experiences, and feel confident about future applications for the technique.

17 SARASOTA 1408 ULTRASONIC GAUGE HANDBOOK

1408 ULTRASONIC GAUGE

HANDBOOK

Issue 0

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Issue Information

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1. INTRODUCTION

The Sarasota 1408 is an open channel water flow gauge or, in its basic form, a velocity meter. Velocity is measured using the ultrasonic "time of flight" method. In order to calculate flow a depth measurement is incorporated from which the cross sectional area is calculated. Flow is then calculated as velocity x area.

It is usual in equipment of this type for velocity to be derived from measurements made by ultrasonic paths at a number of different levels. The 1408 uses one or two paths which may be arranged in a number of ways.

Water level is usually measured by means of an ultrasonic transducer in the water sending a signal upwards and receiving a reflected signal from the surface. However, sometimes the minimum water level is insufficient to allow this method to operate and a separate depth gauge is then employed.

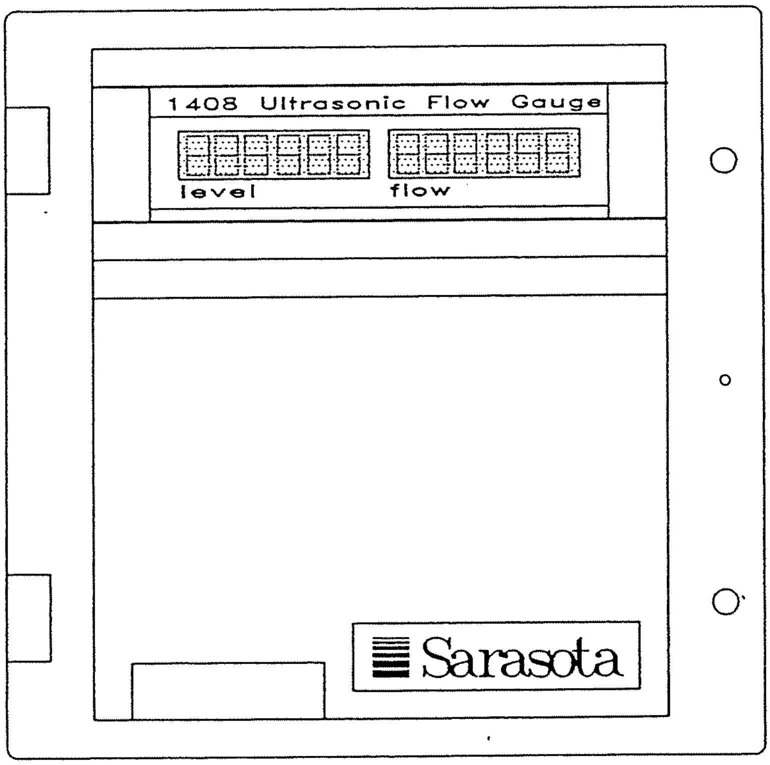


Fig.1 - 1408 Front Showing LCD Displays

The gauge consists of the following units:

- A maximum of two pairs of transducers positioned in the river, one at each end of a path. They may be mounted as a stack or placed individually in the required positions.
- A Depth Sensor such as an ultrasonic transducer, a float operated device or a servo manometer device.

- A Control unit housing the microprocessor, transducer drive and amplifier and system power supply and display.

1.1 Principle of Operation

Pulses of sound are transmitted from each of a pair of ultrasonic transducers fitted on opposite sides of a channel, the path between them being at an angle θ to the flow direction. The apparent velocity of sound upstream is less than that downstream by an amount equal to the resolved component of the average water velocity along the path. The difference in times of flight (*t.o.f*) is usually much less than the transit time itself.

$$\text{Upstream t.o.f.}\ T_u = \frac{L}{c - V\cos\theta}, \qquad \text{Downstream t.o.f.}\ T_d = \frac{L}{c + V\cos\theta}$$

where L is the path length, c is the velocity of sound in water and V is the average water velocity at the level of the path

$$\text{It follows that } V = \frac{c^2\,\Delta T}{2\,L\cos\theta}, \quad \text{where } \Delta T = T_u - T_d \quad \text{provided } c > V$$

c is very dependent on temperature, so it is usual to calculate it from the measured value of the *t.o.f* and the value *L* which is entered into the gauge memory on installation.

$$\text{i.e} \qquad V = \frac{L\,\Delta T}{2\,T^2\cos\theta}, \quad \text{where } T \text{ is the average t.o.f} = \frac{(T_u + T_d)}{2}$$

The method employed by the 1408 to combine two velocity paths into the calculation of flow is given in the Section 1.2. If only one path is used it is important to position it at a level where the water velocity bears a definable and preferably constant relationship to the mean velocity. This is usually not accurately achievable if the water depth varies a lot. The treatment of uncertainties resulting from the use of a limited number of paths is given in ISO 6416.

NOTE: It is important to realise that the overall accuracy of this type of gauge is only partly dependent on the performance of the instrument. Site or installation factors often dominate. To estimate the accuracy of the complete installation, due consideration must be given to all the contributing factors described in ISO 6416.

1.2 Flow Calculation

The following description of flow calculation is based on the bed being at zero height and all the path (transducer) heights being defined relative to it. If a datum other than the mean bed level is being used, e.g. Above Ordnance Datum (AOD), the gauge will apply the offset to all heights, but the calculation remains the same.

The following diagram shows a channel cross section with bed at height zero, paths at H_1 and H_2 and water surface at H. Path lengths are L_1 and L_2 so that the widths at each path are $L_1 \sin\theta_1$ and $L_2 \sin\theta_2$. Mean velocities V_1 and V_2 are calculated as described in section 1.1.

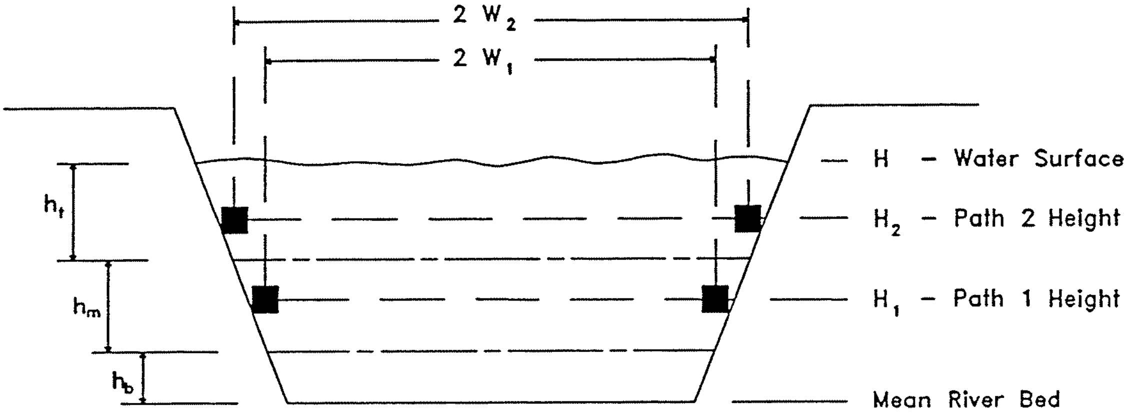


Fig.2 - Channel Cross-section.

3 slices are visualised as follows :-

Top slice corresponding to path 2

with thickness $h_t = H - \dfrac{(H_2 + H_1)}{2}$

and a flow $Q_t = h_t * V_2 * L_2 * \sin\theta_2$

Middle slice corresponding to path 1

with thickness $h_m = \dfrac{(H_2 + H_1)}{2} - \dfrac{H_1}{2} = \dfrac{H_2}{2}$

and a flow $Q_m = h_m * V_1 * L_1 * \sin\theta_1$

Bottom slice related to the velocity measured on path 1

with thickness $h_b = \dfrac{H_1}{2}$

and a flow $Q_b = 0.8 * h_b * V_1 * L_1 * \sin\theta_1$

Total flow $Q = Q_t + Q_m + Q_b$

NOTE:

i. If the two paths are at the same height the above formulae still apply, the bottom slice is assumed to relate to path 1. In this case, $H_1 = H_2$.

ii. The formulae apply whether the paths are in line or crossed.

iii. If there is only 1 path either because only one is installed, or one of two has failed, or the top path is above or too close to the surface, then

$$Q_t = \left(H - \frac{H_p}{2} \right) * V_p * L_p * \sin \theta_p \quad , \quad Q_b = 0.8 * \frac{H_p}{2} * V_p * L_p * \sin \theta_p$$

$$\textit{and} \quad Q = Q_t + Q_b \qquad \textit{where p refers to the working path}$$

iv. In the case of a reflector system, the gauge will take half the path length in order to calculate the slice width.

v. Each path has a "calibration coefficient" which is entered via the GCP and is usually set to one. Examples of cases when another value might be used are:-

Transducers inset from the river banks. Coefficient set > 1 to allow for the flow between the transducers and the banks.

Path heights not at ideal positions relative to the vertical velocity profile. Coefficients used as weighting factors.

vi. The parameters are actually stored in the gauge memory as:-

$$\textit{Velocity factor } (K) = \frac{L * \textit{Calibration coefficient}}{2 \cos\theta}$$

$$\textit{Width factor } (W) = \frac{L \sin \theta}{2}$$

$$\textit{ie.} \quad V * \textit{Calibration coefficient} = \frac{K * \Delta T}{T^2}$$

$$\textit{and} \qquad \textit{Channel width} = W * 2$$

1.3 Power Supply

The power options for the 1408 are :-

1. Mains power (240V ac, 220V ac or 110V ac) fused by the 1408, internal battery (running time approximately 12 hours)
2. External 12V dc power source (battery etc) capable of supplying up to 2A fused by the 1408.

NOTE: Both the mains power supply and the external 12V dc source will charge the internal battery (if fitted). The internal battery will take 36 hours to recharge from the mains power supply after being completely discharged. It will never be completely charged from the external 12V source.

The running time from a battery source is dependant on operation and configuration of the 1408 and state of charge of the battery.

1.4 Optional Depth Input

This option enables an external depth measuring instrument to be connected to the 1408, when there is not enough depth for the integral ultrasonic depth path to work, or for any other reason.

The external instrument must

i. provide a 16 bit parallel output configured as four decades of binary coded decimals (BCDs), of depth in millimetres.

ii. allow the 1408 to control when the depth reading is to be read.

iii. preferably have a resolution of 1 mm or less. (The accuracy of the calculation may be affected otherwise).

1.5 Optional 16 Bit Output

This option enables the 1408 to be connected to a data logger or telemetry device capable of handling up to two 16 bit parallel inputs configured as four decades of binary coded decimals (BCDs). One output will be of depth in millimetres, the other of flow in the same units as the 1408, but coded into the form of multiplier and multiplicand, with an implied decimal point.

1.6 Optional Analogue Output

This option enables the 1408 to be connected to a data logger or telemetry device capable of handling up to two analogue inputs, either 0 to 5 volts or 4 to 20 milliamps. One output will represent the depth reading and the other output the flow reading. The ranges and offsets for each output are programmed into the 1408 on commissioning, or changed by the operator using the PC program, GCP.

2. INSTALLATION

2.1 Site Selection

Recommendations on site selection are given in BS 3680 part 3B (ISO 1100/1).

To summarise briefly, gauging sites should be:-

i. Parallel sided and of fairly constant cross section over the gauging reach and for a distance of 5 times the length of the gauging section upstream.
ii. Not be prone to siltation or scouring.
iii. Not be prone to weed growth (or regular maintenance of the section will be needed).
iv. Be free from upstream discharges which might cause turbulence or entrained air bubbles.
v. Not be subject to tidal back flow which could cause gradients which could bend the ultrasonic beams.
vi. Not be downstream of confluences of water flows of dissimilar temperatures for the same reason. (Nor upstream if there is the possibility of backing up).

2.2 Path Configuration

There are three basic types of path configuration available with the 1408.

1. In-line:	where the upstream transducers of the two velocity paths are on the same side of the channel. Mainly used where the depth varies over a large range and not much skew flow is anticipated.
2. Cross:	where the upstream transducers of the two velocity paths are on different sides of the channel. Mainly used where the depth does not vary much and a fair amount of skew flow is anticipated. The paths tend to be approximately at the same level. This level should be such that 0.6 times the average depth of water is above the transducer path to give the best velocity reading for the channel. It is common to compromise with cross paths where the 2 paths are at different heights. This gives a partial correction for skew flow plus a better cover of the depth range.
3. Reflected:	where the ultrasonic signal is "bounced" off a suitable reflector on the far bank to the other transducer. Mainly used where the channel is small and cables are not easily installed crossing the channel. This configuration is more tolerant to skew flows than the in-line paths but not so good as the cross-paths, but does allow for a greater range of depth than the cross-paths.

2.3 Transducer Mounting and Positioning

The DEPTH transducer should be mounted such that it is transmitting vertically (the transducer axis is vertical), in the area to be gauged.

The VELOCITY transducers (always considered as a pair for each path) should be mounted such that each is transmitting horizontally towards its partner. Care should be used to ensure that adequate clearance (see Table 3) is allowed for between the channel bed and the velocity path height to prevent false reflections interfering with the true signals, and that there is adequate water cover at the minimum depth.

In general, the transducers are inserted into a plastic block, which in turn, is bolted onto the mounting system. Care is needed in devising such a mounting system, to allow for easy alignment and for ensuring that the path is horizontal (or vertical for the depth path).

2.4 Control Unit Mounting

2.4.1 Pole Mounted

Place the mounting pole in the ground, vertically, near the section to be gauged such that 1 m to 1.5 m of pole is out of the ground. The outside diameter of the pole should be in the range 25 mm to 80 mm.

Bolt one of the bracket pairs on to the pole, near the top, using the M8 x 130 mm bolts, as shown in Figure 3. Making sure that the cut out is uppermost and is away from the channel and the partnering bracket has the bolt access holes aligned up with the cut out. Now bolt the second bracket pair about 310 mm below the first, keeping it in the same orientation. Ensure that the bolts are tightened enough to hold the enclosure on to the pole but not so tight as to strip the threads or bend the brackets.

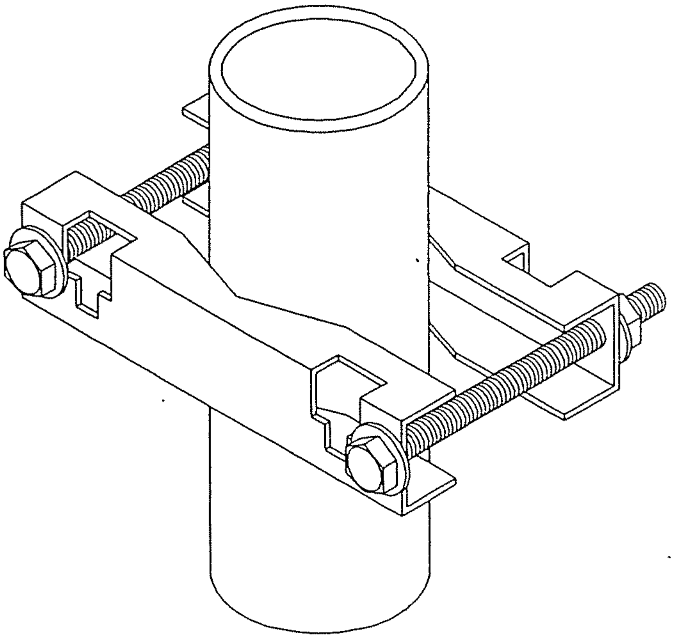


Fig.3 - Pole Mounting Bracket

The enclosure can now be suspended from the brackets using the M8 x 20 mm bolts, which should pass through the cut out in the brackets and sit on the bottom of the slot, before being tightened.

2.4.2 Wall Version

Secure the wall mounting plate to the wall, using M8 fixings, such that the strip joining the two cut out bars is vertical and that the cut outs are uppermost.

The enclosure can now be suspended from the plate using the M8 x 20 mm bolts, which should pass through the cut out in the plate and sit on the bottom of the slot, before being tightened.

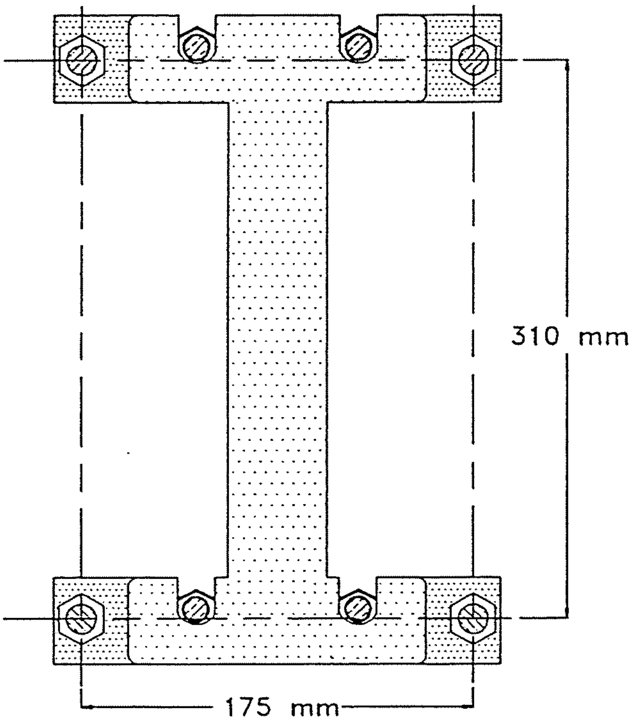


Fig.4 - Wall Mounting Bracket

2.5 Cabling and Connections

The transducer and power cables are routed via separate conduits into the 1408 enclosure. The transducer cables can be passed through the left-hand gland with the BNC plugs fitted, but in general the cables need to be passed through before connectors can be fitted.

The power cables, which pass through the right-hand gland are connected directly to the terminal blocks in the bottom right-hand compartment. See Fig.5 for location of connections.

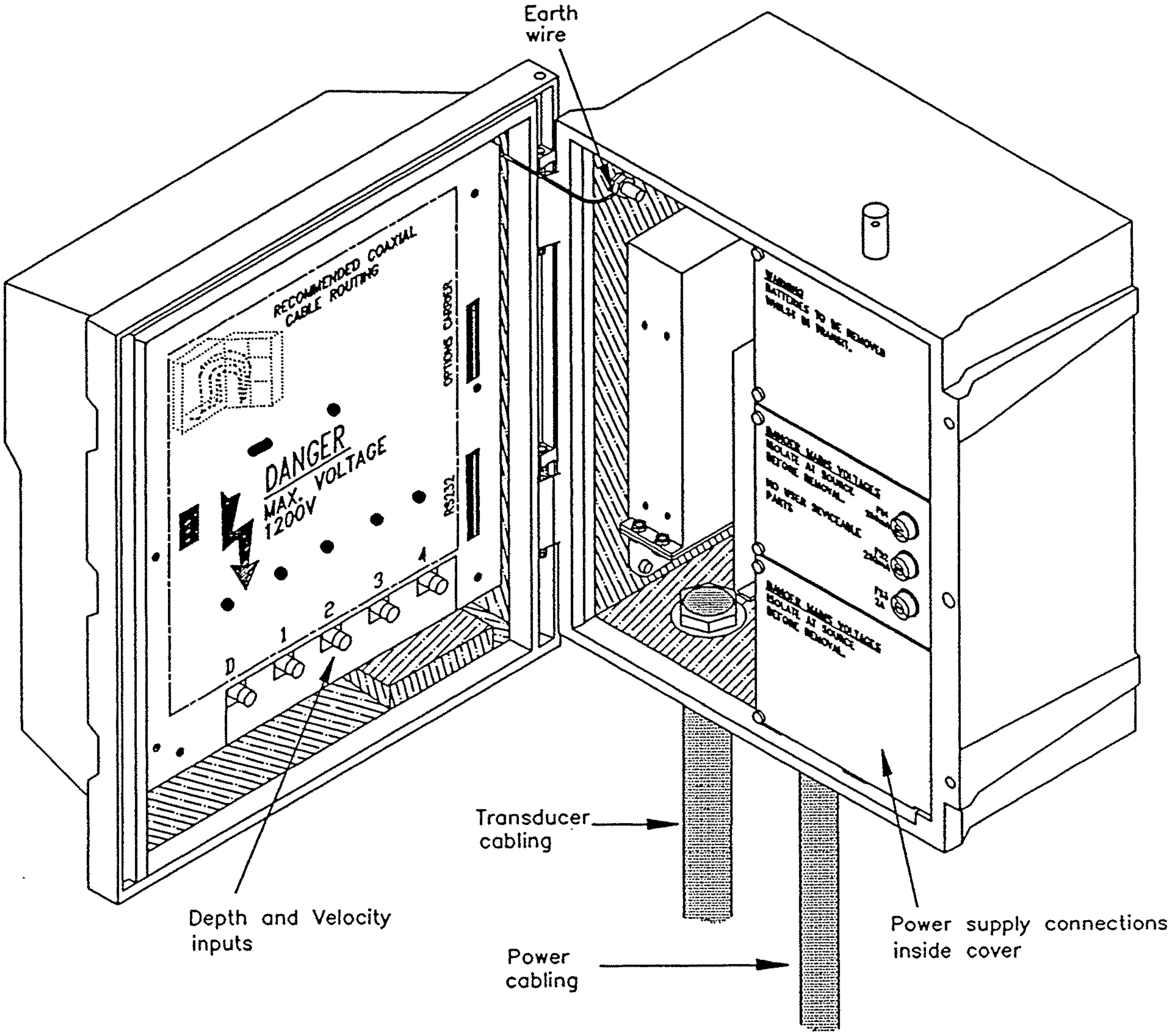


Fig.5 - 1408 Internal View showing Connectors.

2.5.1 Conduit Connection

If necessary, the conduit should be cut to length. The conduit clamping nut should be unscrewed and removed from the enclosure along with the plastic seal and metal insert.

The conduit should then be passed through the clamping nut (nut end first) followed by the plastic seal (smaller end first). The metal insert should be screwed into the conduit until the step is flush with the conduit. The plastic seal should be pulled until it meets the metal insert and clamping nut up to the step on the seal. Now the conduit can be screwed fully into the fitting on the enclosure and fixed to the wall or pole.

2.5.2 Mains Cabling

The mains cable should be rated to be 2A, 240V ac. It should be connected to the 6-way mains terminal block via the right-hand gland. The connections are as follows:-

110V link TB1/1 to TB1/4
link TB1/2 to TB1/5
link TB1/3 to TB1/6
connect LIVE (brown) to TB1/1
connect NEUTRAL (blue) to TB1/3
connect EARTH (yellow/green) to TB1/2

240V link TB1/2 to TB1/5
link TB1/3 to TB1/4
connect LIVE (brown) to TB1/1
connect NEUTRAL (blue) to TB1/6
connect EARTH (yellow/green) to TB1/2

NOTE: TB1 is the furthest left.

The 1408 has some protection against the power source being incorrectly installed, but damage can still occur. It is important that the gauge is properly earthed and that it is fused externally to the unit.

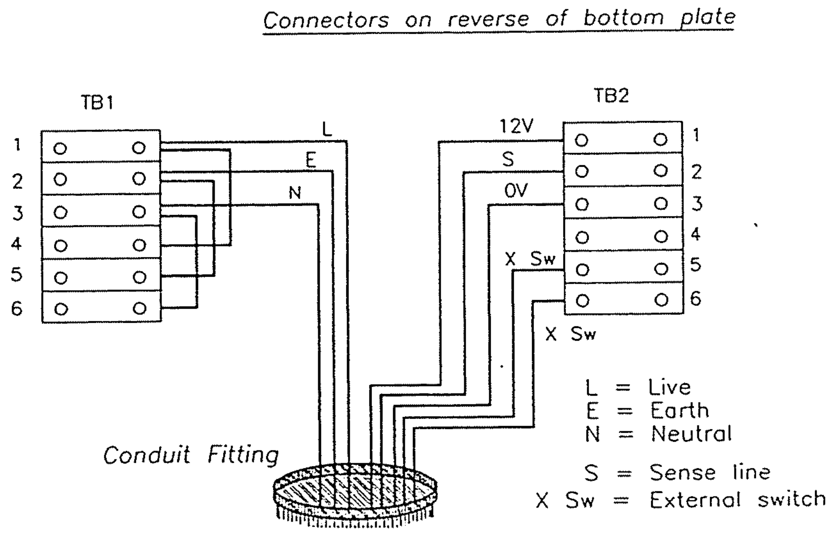


Fig.6 - Power Supply Connections for 120V/110V and 12V External Power Source.

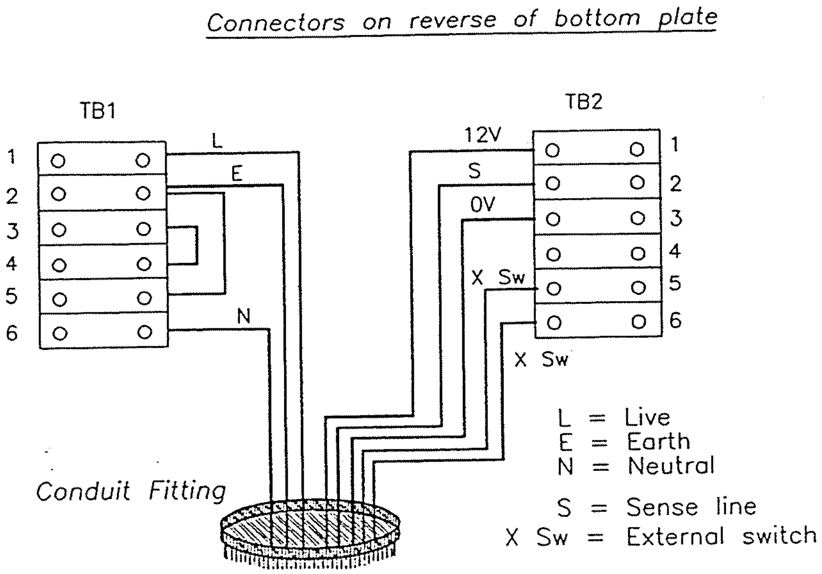


Fig.7 - Power Supply Connections for 220V/240V and 12V External Power Source.

2.5.3 External Power Source

The minimum rating for the external 12V supply cable is 3A, 20V dc. The cable enters the bottom right-hand compartment of the enclosure via the right hand gland and is connected to the auxiliary terminal block as follows:

connect 12V to TB2/1
connect 0V to TB2/3

if there is a sense line this should be connected to TB2/2.

2.5.4 Internal Batteries

The two internal batteries must be removed from the top compartment inside the 1408 case whilst it is in transit, and on installation should be connected as follows.

Connect in series, using the battery cable as supplied. Two wires are routed to the battery compartment for connecting into the system and are identified as follows:-

brown = positive (fitted with an in-line 3A fuse)

black = negative

2.5.5 Interrupt Switch Option

A volt-free contact may be connected to the auxilliary terminal block at TB2/5 and TB2/6. This is used to remove power from the 1408 boards.

2.5.6 Supply to Boards

The 12V supply to the boards is protected by fuse FS3 rated at 2A.

2.5.7 Transducer Connections

The cable used to connect the transducers is normally URM76 which can withstand up to 700V between inner and outer conductors.

The transducer measuring depth must be connected to the BNC socket marked "D".

The lower velocity path transducer, or the only one in single path systems, must be connected to the BNCs marked "1" and "2" and the higher velocity paths to the BNCs marked "3" and "4".

Before powering up the 1408, select the approximate voltage required to drive the transducer (see Table 1) and set the receiver amplifier's gain to minimum by setting Link 8 across A-C and setting Switch 1 to 1.

PATH LENGTH	TRANSDUCER DRIVER VOLTAGE
1.5 to 50 metres	180 - 220 v (make link Lk3)
50 to 100 metres	360 - 440 v (make links Lk2 & Lk5)
100 to 150 metres	540 - 660 v (make links Lk1, LK4 & Lk5)
	NOTE: Break the unlisted links Lk1 - Lk5

Table 1 - Path Length and Transducer Driver Voltage Values (factory set to mid-range)

2.6 Setting Up

With the transducers in the channel, measure and record the following items:

ITEM		RECORDED VALUE
Configuration		In-Line / Cross Path / Reflected
Height Reference Level		Mean River Bed / AOD / other ref...............
Height of Mean River Bed		metres
Level of the Zero crossing of the Digital Depth Input		metres
Flow Units		Cumecs / Ml/d
Approximate Cable Lengths	- Near	metres
	- Far	metres
Depth Input		Internal / Auxiliary
Minimum Depth of Water Above Depth Path		milli seconds
Depth Path Heights		metres
Calibration Coefficient		
Maximum Height		metres
Number of Velocity Paths		1 / 2
Minimum Depth of Water Above Velocity Paths		metres
Maximum Time Difference	- Path L	milli seconds
	- Path H	milli seconds
Certification	- Path L	
	- Path H	
Velocity Path Heights	- Path L	metres
	- Path H	metres
Velocity Path Length	- Path L	metres
	- Path H	metres
Calibration Coefficient	- Path L	
	- Path H	
Angle to Flow	- Path L	degrees
	- Path H	degrees

Where Path L is the lower of the velocity paths and Path H, the higher.

Table 2 - Recorded Set-Up Values

3. OPERATION

3.1 One Minute Cycle

The 1408 operates on a one minute cycle. During this cycle the horizontal paths and, if applicable, any ultrasonic depth paths are sampled in turn as quickly as possible. A maximum of 255 samples are taken for any one path from which velocity is determined and flow calculated.

3.2 Automatic System Tests

Every fifteen minutes the following three tests are automatically performed on the system.

3.2.1 Transducer Ring Test

This check detects damage or abnormalities to the transducers. If a transducer fails to ring or rings in a different manner to normal it is an indication of possible damage or the transducer being out of the water. The signal generated by the transducer is sampled for a period of 50 micro seconds after a specified time from its firing. The test fails if no signals rise above 0.3V and fall below zero in that period.

3.2.2 Delay Test

This measures the time taken for an electronic signal to pass from the computer interface out along the cables, via the high power transmitter circuit, to the transducer, and back via the amplifier to the signal detector in the computer interface. It is a measure of the speed of the electronic circuits, and since the delay will be affected by cable lengths, the expected value will be different for each site and may be different for individual paths.

3.2.3 Clock Test

This compares the accuracy of the clock in the path timing system with that used in the microprocessor.

NOTE: The signals seen at ‘firing time’ are affected by many factors including the mounting system, silt etc. Consequently the ring and delay tests are a useful guide but not a 100% reliable indication of correct transducer operation.

3.3 Displays

The 1408 has two LCD displays, each capable of displaying six digits. They will alternate between showing the flow and depth readings or the individual velocity readings.

The current calculated fifteen minute average flow reading appears in the right hand display and will show the calculated flow in the channel, up to six digits, to three decimal places or to one decimal place depending on whether cubic metres per second (cumecs) or megalitres per day (Ml/d) respectively have been selected.

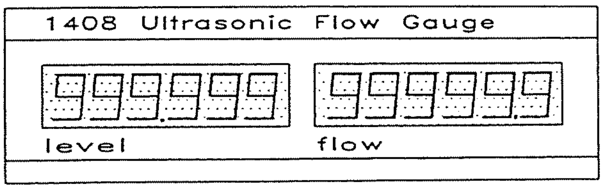


Fig.8 - Level and Flow Display (Flow in Ml/d))

The current depth reading appears in the left hand display and will show the depth, up to six digits, to three decimal places in metres, to the programmed reference level.

The current velocity readings can be found on the alternate display. The velocities are displayed, as four digits, to three decimal places in metres per second (m/s). The lower path (or only path in a one path gauge) velocity reading will appear in the left hand display with an "L" preceding the value and the higher path velocity reading in the right hand display with an "H" preceding the value.

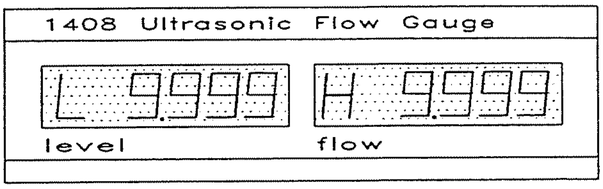


Fig.9 - Velocity Display

Note if the higher path has not been installed its reading should be ignored.

If any of the readings are in error, (either too big, not measured or any other reason) the displayed reading will show all nines. (For flow 999.999 or 99999.9, depth 999.999 and velocity 9.999).

3.4 Transducer Frequency Selection

The transducer frequency to be used depends on the path length of the ultrasonic signal and the amount of suspended solids in the water (see Table 3). With the velocity paths, the path length will depend on the width of the channel and the angle of the signal to the channel flow, whilst a 500 KHz transducer used on the depth path, will give an acceptable level measurement, with a water cover of 0.3 m to 15 m.

NOTE: Not all the described transducer frequencies are currently available from Peek Measurement, please refer to the latest data sheet for the present range.

Typical minimum path length, L	Typical minimum cover, h	Operating frequency for ± 0.015 m/s uncertainty
m	m	KHz
300	3 to 5	50 to 100
150	2 to 3	100 to 200
80	1	200 to 300
30	0.3	300 to 500
10	0.15	500 to 1000
3	0.1	1000 to 2000

NOTE: Minimum cover h is based on requiring any reflected signals to arrive at least one wavelength behind the direct arrival.
The formula for the minimum cover, h is $h - \sqrt{\frac{Lc}{2f}}$

where L is the path length,
c is the velocity of sound
f is the transducer frequency.

Table 3 - ISO6416 Values for Path Length, Cover and Operation Frequency

The depth path requires the transducer to be covered with at least 300 mm of water. If there is not enough depth for the integral ultrasonic depth path to work, an external depth measuring instrument should be connected to the 1408 using the optional depth card.

3.5 Programming

3.5.1 Entering Site Variables

These are entered via the GCP program - see Section 4 for details.

3.5.2 Setting the Receiver Amplifier

The received signals from the transducers may be monitored using a Dual Beam/Dual Time Base with Delay Oscilloscope.

Set the scope to use the Main Timebase and trigger it on the negative going edge of the signal at the selected test point (see Table 4).

TRANSDUCER BEING MONITORED	TRIGGER SIGNAL FOR O'SCOPE
Depth	TP17
Transducer 1	TP18
Transducer 2	TP19
Transducer 3	TP20
Transducer 4	TP21

Table 4 - Selecting the Test Point for Triggering the Scope.

Using the scope, monitor the gate signal (Test Point 14) with one probe and amplifier output (Test Point 10) with the other. Alter the main timebase until the trace is similar to Figure 6.

The scopes vertical amplifiers should be set to 5 volts per division for the Gate Signal and 1 volt per division for the Amplifier Recieved Signal. Note it may not be possible yet to see the received signal with this amplifier setting.

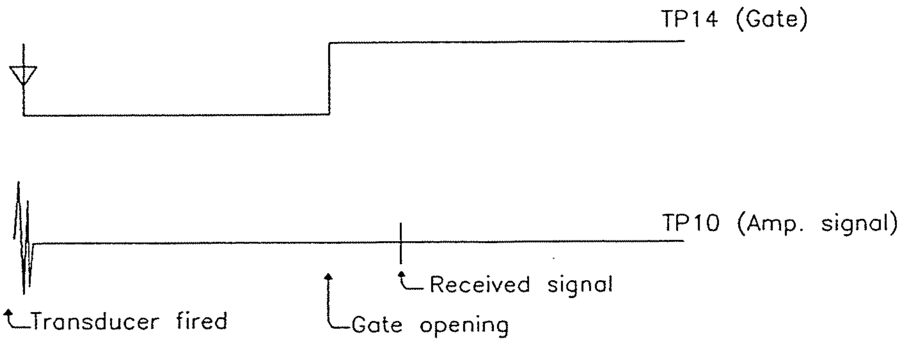


Fig.10 - Oscilloscope Trace

Initially set the Delayed Timebase setting to start just before the Gate Opening and to last for approximately one eighth of the Main Timebase setting.

Then switch the scope to use Delayed Timebase and view only the amplified signal. The trace on the scope should show the signal expanded, and the scopes vertical amplifier gain may be increased until a received signal can be seen.

Alter the delay for the timebase until the amplified received signal is at the left hand end of the trace. The Delayed Timebase can now be increased until individual excursions of the received signals can be seen.

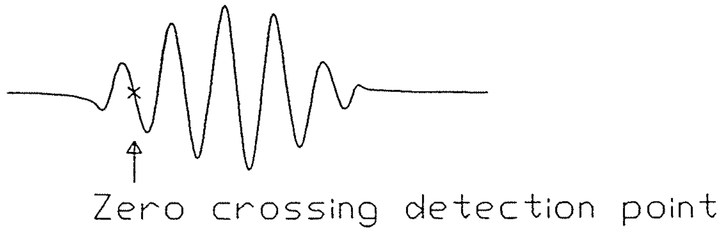


Fig.11 - Received Signal

The zero crossing detector is triggered by the positive excursion part of the signal passing through 0.25V.

The receiver amplifier gain should be increased so that the following conditions are met:-

i. Depth Path

The received signal must have an amplitude of more than 0.25V before falling through zero, but the waveform shape is not taken into account as there may be phase changes due to ripples on the water surface.

ii. Velocity Paths

The received signal is deemed good if it does not go below -1V before going in excess of +0.5V and if after going positive by more than +0.25V it exceeds +0.5V before going negative.

The received signal is deemed of low amplitude but still usable if it does not pass through 0.5V before falling through zero and does not pass through -1V.

The amplifier gain is increased by closing the DIL switch segments as shown in Table 5.

GAIN ADJUSTMENT		
SWITCH	LK8 O/C i.e. link A-C	LK8 S/C i.e. link A-B
All open	40 dB	60 dB
Close 1 (a)	46 dB	60 dB
& Close 1 (b)	49.5 dB	69.5 dB
& Close 1 (c)	52 dB	72 dB
& Close 1 (d)	55.5 dB	75.5 dB
& Close (e)	58 dB	78 dB
& Close (f)	60 dB	80 dB

NOTE: LK8 IS NORMALLY O/C.

Table 5 - Increasing Amplifier Gain

If the background noise is more than 0.2V p-p increase the settings of the transducer driver voltage either by altering the individual adjusters on the DC-DC converter or by altering the links Lk1 - Lk5, to add another converter to the circuitry.
It may be necessary to make further adjustments to the transducer alignment or investigate reasons for the sound being blocked.

NOTE: The more converters in use, the more current is being drawn from the supply and hence the operational time for batteries will be shortened.

3.6 Viewing Results

The gauge has two LCD displays showing flow and depth readings as well as velocity readings, but in order to read all data and results collected by the 1408 or to view or change preset variables the gauge must be connected to an IBM or compatible PC and the communicator program GCP run. (See Section 4).

NOTE: The data collecting period is one minute, therefore a short period will elapse before the system settles down.

4. COMMUNICATOR PROGRAM

4.1 Introduction

The gauge communicator program (GCP) will run on an IBM PC or compatible and communicate with the 1408. It allows site dependant data to be entered, current status of the 1408 and the quantities measured to calculate current values to be inspected.

The minimum configuration of PC required to run the GCP program is as follows:-

- 512K bytes of memory
- one floppy disk drive
- a monochrome display adapter
- serial communications port.

NOTE: The PC serial port should be wired as a DTE device, i.e. that Pin 2 of the port is used as an output from the PC. If not a cross-over link is required to change the port from a DCE to a DTE device.

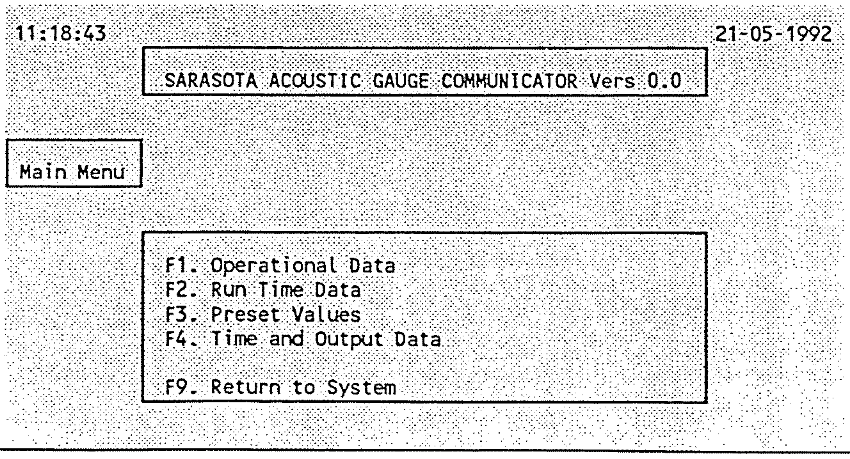
4.2 Connecting the PC to the 1408

The "D" connector of the GCP cable should be connected to the serial port marked COM1 on the PC. The other end of the GCP cable is the 26-way ansley connector which should be plugged in to the RS232 port inside the door assembly of the 1408. (Refer to Fig.5). Pin 1 of the connector must be uppermost.

4.3 Running GCP

Type the letter of the drive on which GCP is to be found (e.g. A: if running from floppy disk) then type GCP and depress ENTER to run the program. If running from the default hard disk drive then the drive letter may be omitted.

The program will initially request whether the monitor is colour or not. If yes, type "Y" otherwise type "N".
The display then shows the Main Menu, from which four types of data can be collected.



```
11:18:43                                                   21-05-1992
            SARASOTA ACOUSTIC GAUGE COMMUNICATOR Vers 0.0

Main Menu

            F1. Operational Data
            F2. Run Time Data
            F3. Preset Values
            F4. Time and Output Data

            F9. Return to System
```

Operational (or site) data is accessed using function key 1 (F1). This will show the values used by the 1408 to calculate the velocities, depth, flow etc.

Use F2 to display values calculated by the 1408 and current status.

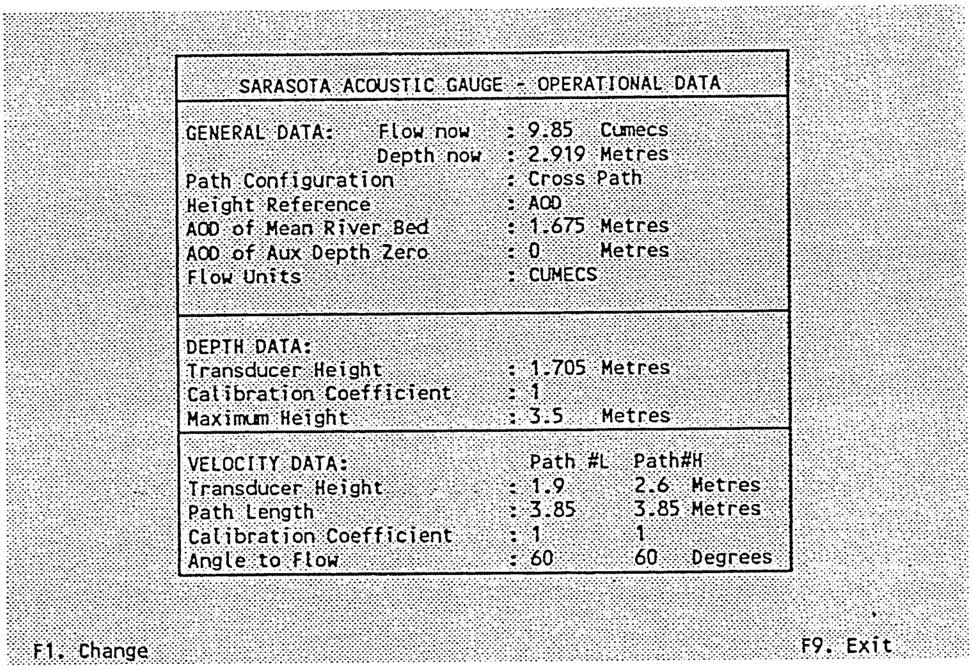
F3 will display values required by the 1408 to operate the fitted hardware.

F4 will access the date and time and the ranges for analogue output(s).

Depressing F9 from this menu will exit GCP and return to DOS.

4.3.1 Operational Data

The Operational Data display shows general data, depth data and velocity data.



```
          SARASOTA ACOUSTIC GAUGE - OPERATIONAL DATA

GENERAL DATA:     Flow now    : 9.85   Cumecs
                  Depth now   : 2.919  Metres
Path Configuration            : Cross Path
Height Reference              : AOD
AOD of Mean River Bed         : 1.675  Metres
AOD of Aux Depth Zero         : 0      Metres
Flow Units                    : CUMECS

DEPTH DATA:
Transducer Height             : 1.705  Metres
Calibration Coefficient       : 1
Maximum Height                : 3.5    Metres

VELOCITY DATA:                  Path #L  Path#H
Transducer Height             : 1.9      2.6  Metres
Path Length                   : 3.85     3.85 Metres
Calibration Coefficient       : 1        1
Angle to Flow                 : 60       60   Degrees

F1. Change                                              F9. Exit
```

The flow and depth values are the current 1 minute average values.

The path configuration describes how the velocity transducers have been installed - either IN-LINE, CROSS-PATH or REFLECTED.

Three selections are available as height references. If the Mean River Bed is selected, the height reference is automatically set to zero and cannot be changed.

If AOD is selected then an offset value is required for both the Mean River Bed and auxiliary depth. This offset value is used to relate the depth to other installations used.

If "other ref" is selected an offset value is required but this does not relate the depth on other installations.

Flow readings can be calculated either in cubic metres per second (CUMECS) or in megalitres per day (Ml/d). If the units are changed whilst the 1408 is in use, then the average values will be erroneous until the end of the averaging period. i.e. 15 minute average flow will be incorrect until 15 minutes have elapsed since the last change of units.

The maximum height for the depth path is entered as a check against false signals from the depth transducer or misreading of the auxiliary depth input causing incorrect flow values.

Where two velocity paths are installed Path L is the lower of the two and Path H the higher. Path L is used if only one velocity path is installed.

The values entered for path length, angle to flow and calibration coefficient along with the path configuration are used by GCP to calculate Velocity factor (K) and Width factor (W). These factors are communicated to the 1408 for use in calculating velocities and flows.

Pressing F9 returns the operator to the Main Menu.

4.3.2 Changing Displayed Values

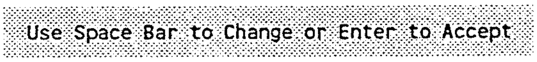
F1 should be depressed to enable changing of values. When F1 is pressed GCP directs the user on how to change or accept each of the values, which are highlighted in turn by a cursor bar.

If a numeric value is required it will prompt

Press Enter to accept or enter new value

The value should be entered and the ENTER key depressed to enter the number. The BACKSPACE key may be used to remove incorrectly entered digits.

If the available options are limited to known units or values the prompt will show



Use Space Bar to Change or Enter to Accept

Using the SPACE BAR will toggle the operator through the options available, and the ENTER key should be pressed when the correct value is displayed.

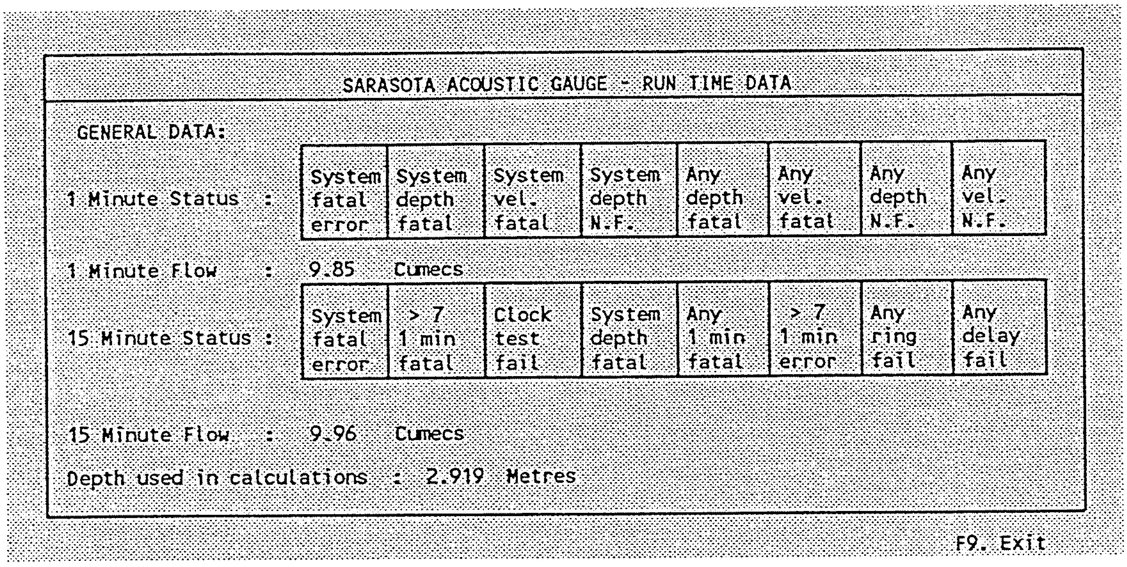
In both the above cases pressing the ENTER key to accept a displayed value will also cause the cursor bar to move on to the next value to be changed.

4.3.3 Run Time Data Menu

From the Main Menu the Run Time Data menu can be displayed by pressing F2. This menu gives four options:-

View General Data
View Depth Data
View Velocity Data
Return to Main Menu.

F1 will access View General Data with a display similar to the following:-



SARASOTA ACOUSTIC GAUGE - RUN TIME DATA

GENERAL DATA:

1 Minute Status :	System fatal error	System depth fatal	System vel. fatal	System depth N.F.	Any depth fatal	Any vel. fatal	Any depth N.F.	Any vel. N.F.

1 Minute Flow : 9.85 Cumecs

15 Minute Status :	System fatal error	> 7 1 min fatal	Clock test fail	System depth fatal	Any 1 min fatal	> 7 1 min error	Any ring fail	Any delay fail

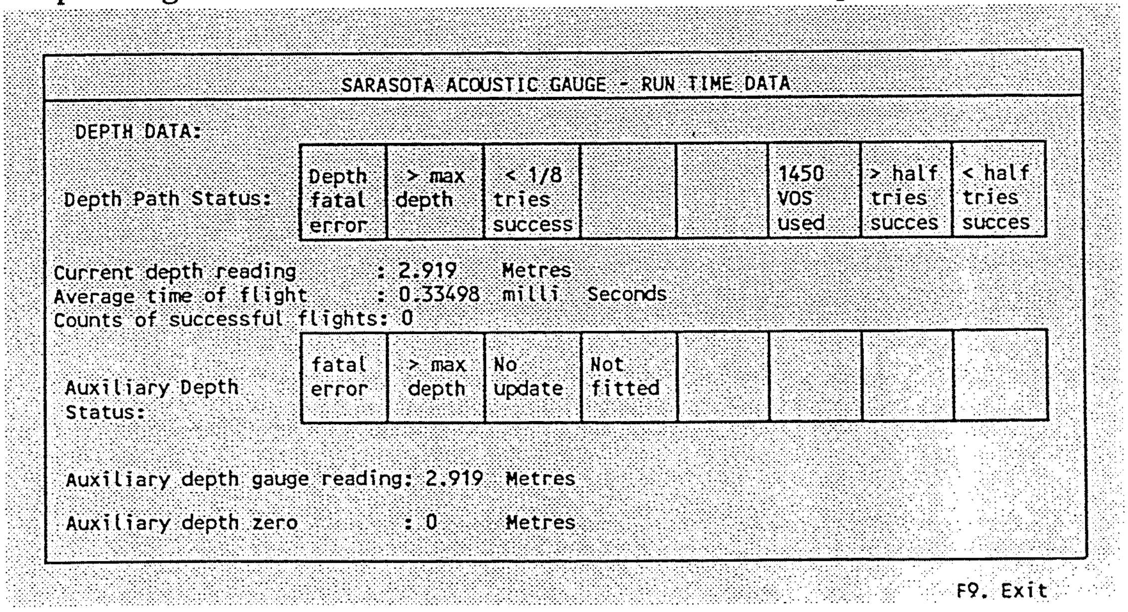
15 Minute Flow : 9.96 Cumecs

Depth used in calculations : 2.919 Metres

F9. Exit

The boxes show the error messages that the 1408 can detect and store in the 1 minute and 15 minute flow status. See Section 4.4.

Depressing F2 from the Run Time menu causes the Depth Data to be displayed.



SARASOTA ACOUSTIC GAUGE - RUN TIME DATA

DEPTH DATA:

Depth Path Status:	Depth fatal error	> max depth	< 1/8 tries success			1450 VOS used	> half tries succes	< half tries succes

Current depth reading : 2.919 Metres
Average time of flight : 0.33498 milli Seconds
Counts of successful flights: 0

Auxiliary Depth Status:	fatal error	> max depth	No update	Not fitted				

Auxiliary depth gauge reading: 2.919 Metres

Auxiliary depth zero : 0 Metres

F9. Exit

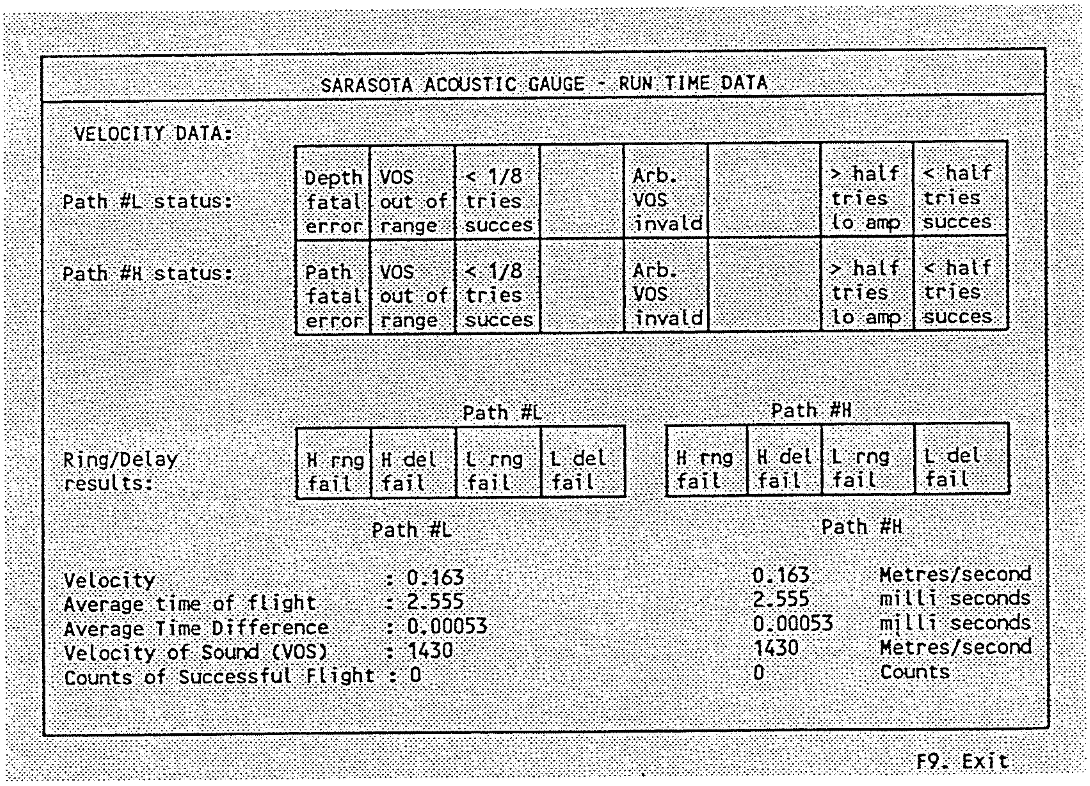
Again all possible error messages are shown in the boxes. Refer to Section 4.4.

The average time of flight is the average time taken for the ultrasonic signal to travel from the depth transducer up to the water surface and back again.

The count of successful flights is the number of successful attempts at measuring the time of flight during the one minute sampling period. With each successful flight the count is increased by the 1408, but GCP requests a new value from the 1408 every second, making the value appear to increase in steps of three or more. The maximum number of attempts is 255, but may be less, dependant on the path lengths of all the ultrasonic paths operated by the 1408.

This display is shown until F9 is depressed to return to the Run Time menu.

If the F3 key is depressed from the Run Time menu Velocity Data is displayed.



```
                   SARASOTA ACOUSTIC GAUGE - RUN TIME DATA

 VELOCITY DATA:
                      Depth  VOS     < 1/8          Arb.            > half  < half
 Path #L status:      fatal  out of  tries          VOS             tries   tries
                      error  range   succes         invald          lo amp  succes

 Path #H status:      Path   VOS     < 1/8          Arb.            > half  < half
                      fatal  out of  tries          VOS             tries   tries
                      error  range   succes         invald          lo amp  succes


                                  Path #L                     Path #H
 Ring/Delay           H rng  H del   L rng  L del      H rng  H del  L rng   L del
 results:             fail   fail    fail   fail       fail   fail   fail    fail

                           Path #L                            Path #H

 Velocity                       : 0.163                        0.163     Metres/second
 Average time of flight         : 2.555                        2.555     milli seconds
 Average Time Difference        : 0.00053                      0.00053   milli seconds
 Velocity of Sound (VOS)        : 1430                         1430      Metres/second
 Counts of Successful Flight    : 0                            0         Counts

                                                                         F9. Exit
```

The example shows all the error messages that the 1408 can detect and store for the velocity path status. See Section 4.4.

The average time of flight is the average time taken for the ultrasonic signal to go from one transducer of a velocity path pair to the other.

The average time difference is the average difference between the flight time upstream and the flight time downstream.

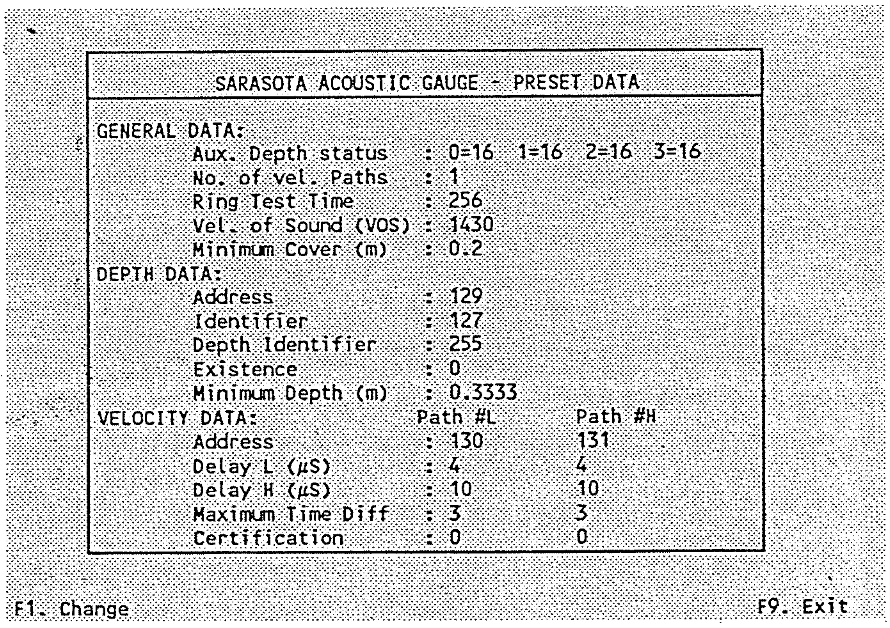
The count of successful flights is the number of successful attempts to measure the time of flight during the minute sampling period. With each successful flight the count is increased by the 1408 but, because GCP requests a new value from the 1408 every second, it may appear to increase in value in steps of three or more.
The maximum number of attempts is 255, but may be less depending on the lengths of the ultrasonic paths operated by the 1408.

This display is shown and continually updated until F9 is depressed to return to the Run Time menu.

A further depression of F9 will return the user to the Main menu.

4.3.4 Preset Data

Depressing F3 from the Main Menu will display the Preset Data values.



```
                SARASOTA ACOUSTIC GAUGE - PRESET DATA

GENERAL DATA:
         Aux. Depth status    : 0=16  1=16  2=16  3=16
         No. of vel. Paths    : 1
         Ring Test Time       : 256
         Vel. of Sound (VOS)  : 1430
         Minimum Cover (m)    : 0.2
DEPTH DATA:
         Address              : 129
         Identifier           : 127
         Depth Identifier     : 255
         Existence            : 0
         Minimum Depth (m)    : 0.3333
VELOCITY DATA:                Path #L       Path #H
         Address              : 130         131
         Delay L (µS)         : 4           4
         Delay H (µS)         : 10          10
         Maximum Time Diff    : 3           3
         Certification        : 0           0

F1. Change                                                  F9. Exit
```

The auxiliary depth status shown under General Data is the status of the non ultrasonic depth inputs. This is provided by the optional depth input, of which only depths 0 and 1 are available.

To disable the auxiliary depth input enter 16.

To enable the auxiliary depth input enter 0.

The value 1 or 2 should be entered for the number of velocity paths as appropriate.

Minimum cover is the minimum amount of water needed to cover the velocity transducers before the system can use data from the path without reflections interfering with the received signal. Refer to Section 3 Operation for calculation of minimum cover.

The minimum depth is the minimum amount of water covering the depth transducer, that can be measured by the 1408.

Maximum time difference is the maximum velocity multiplied by path length divided by 1450^2 in units of 25 μs. This value must be greater than or equal to 2. For example, if the water velocities in excess of 3 metres/second are to be ignored, then the value to be entered is path length * 0.05.

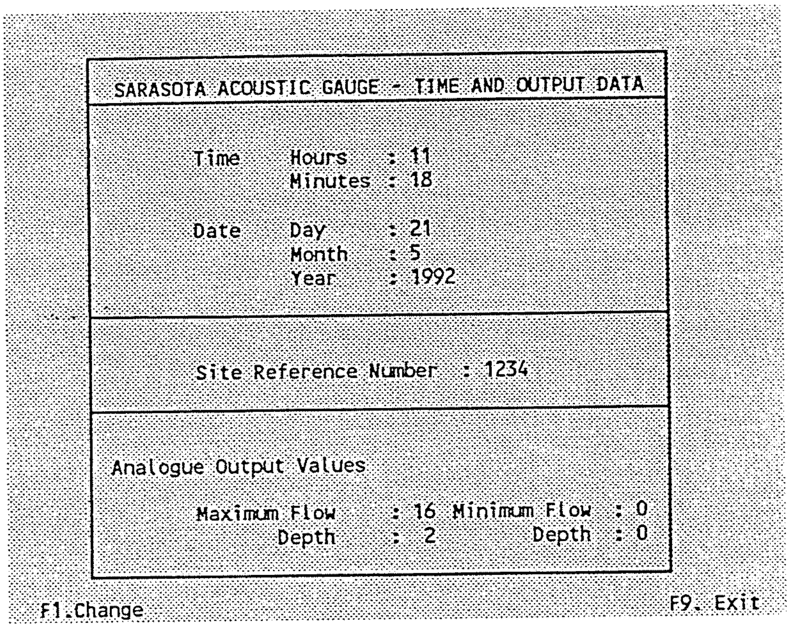
Certification is entered 0 if the path is free from false reflections, otherwise 255 should be entered. If 255 is entered the system will not use data from that path for determining the average velocity of sound in water (VOS) value and if no velocity paths are free from false reflection the VOS used in depth calculation will always be 1450 m/s.

The other values describe to the software what hardware is installed and hence should not be changed.

To change variable values refer to Section 4.3.2. To return to the Main Menu depress F9.

4.3.5 Time and Output Data

From the Main Menu pressing F4 displays the time and output data.



```
SARASOTA ACOUSTIC GAUGE - TIME AND OUTPUT DATA

        Time     Hours   : 11
                 Minutes : 18

        Date     Day     : 21
                 Month   : 5
                 Year    : 1992

        Site Reference Number  : 1234

Analogue Output Values

        Maximum Flow    : 16  Minimum Flow  : 0
                Depth   : 2          Depth  : 0
F1.Change                                      F9. Exit
```

The date and time can be altered if necessary and a site reference number entered to discriminate between various sites.

The analogue output values determine the ranges presented by the analogue output card when fitted. E.g. if an analogue card is fitted to the 1408 options carrier, the output will be either:

i. Current 4 mA, Voltage 0V if less than or equal to the minimum value.

ii. Current 20 mA, Voltage 5V if greater than or equal to the maximum value.

iii. Current $(\frac{Reading-\mathrm{min}}{\mathrm{max}-\mathrm{min}}*16) + 4\ mA$, Voltage $\frac{Reading-\mathrm{min}}{\mathrm{max}-\mathrm{min}}*5V$ if between the two values.

This display remains until either F1 is depressed to change values as per Section 4.3.2 or F9 is depressed to return to the Main Menu.

For more information on these outputs refer to Section 1.6.

4.4 Error Messages

The screen displays for the Run Time Data menu options all contain the error messages stored by the 1408. In general there are two categories of error: fatal or non-fatal.

A FATAL error is one which indicates the value to which it refers cannot be guaranteed correct and therefore affects flow calculation, whereas a NON-FATAL error indicates a fault is present but is not serious enough to cause an error in the flow reading.

4.4.1 General Data Error Messages

One Minute Status

SYSTEM FATAL ERROR -	a general error in reading velocity or depth. Flow calculation invalid.
SYSTEM DEPTH FATAL -	error in reading the ultrasonic depth. Flow calculation invalid.
SYSTEM VELOCITY FATAL -	reading of velocity paths faulty. Flow calculation invalid.
SYSTEM DEPTH NON-FATAL -	errors reading depth, but valid readings still obtained. Flow calculation valid.
ANY DEPTH FATAL -	the ultrasonic and auxiliary depth readings are in error. Flow calculation invalid.
ANY VELOCITY FATAL -	one of the velocity paths is in error. Flow calculation invalid if only one path used.
ANY DEPTH NON-FATAL -	one of the depth paths is in error but readings still valid. Flow calculation valid.
ANY VELOCITY NON-FATAL -	one of the velocity paths is in error but valid readings still obtained. Flow calculation valid.

Fifteen Minute Status

SYSTEM FATAL ERROR -	as for One Minute Status.
>7 1 MINUTE FATAL -	more than half of One Minute errors have been fatal.
CLOCK TEST FAIL -	a test on the measuring clock has revealed a fault or failure.
SYSTEM DEPTH FATAL -	as for One Minute status.
ANY 1 MINUTE FATAL -	a system fatal error has occurred under the One Minute status.
>7 1 MINUTE ERROR -	more than half of One Minute errors have been non-fatal.
ANY RING FAIL -	a failure has occurred in one or more transducer tests.
ANY DELAY FAIL -	a failure has occurred in the timing of the hardware.

4.4.2 Depth Data Error Messages

Depth Path Status

DEPTH FATAL ERROR -	ultrasonic depth reading faulty causing errors in depth value. Flow calculation invalid.
> MAX DEPTH -	depth reading obtained greater than maximum depth configured.
< 1/8 TRIES SUCCESS -	less than one eighth of depth scans have been successful.
1450 VOS USED -	default Velocity of Sound value in use (one or more velocity paths lost).
> HALF TRIES LO AMP -	more than half of the scans have returned a low signal.
< HALF TRIES SUCCESS -	less than half the scans have returned valid readings.

Auxiliary Depth Status

FATAL ERROR -	as for Depth path status.
> MAX DEPTH -	as for Depth path status.
NO UPDATE -	no reading returned.
NOT FITTED -	Auxiliary depth selected but not fitted.

4.4.3 Velocity Data Error Messages

Path #L & Path #H status

DEPTH FATAL ERROR -	the u/s depth reading is faulty, causing error in depth value. Flow calculation invalid.
VOS OUT OF RANGE -	Velocity of Sound measurement is greater than maximum value configured.
<1/8 TRIES SUCCESSFUL -	less than one eighth of the total scans have been successful.
ARB. VOS INVALID -	Velocity of Sound is outside allowed range.
> HALF TRIES LO AMP -	more than half the scans have returned a low signal.
< HALF TRIES SUCCESS -	less than half the scans have returned valid readings.

Ring/Delay Results (for both paths)

H RNG FAIL -	upstream transducer test fail
H DEL FAIL -	upstream transducer test fail
L RNG FAIL -	downstream transducer test fail
L DEL FAIL -	downstream transducer test fail

5. FAULT DIAGNOSIS

WARNING disconnect gauge from mains supply and disconnect 12V source where used, before removing any fuses.

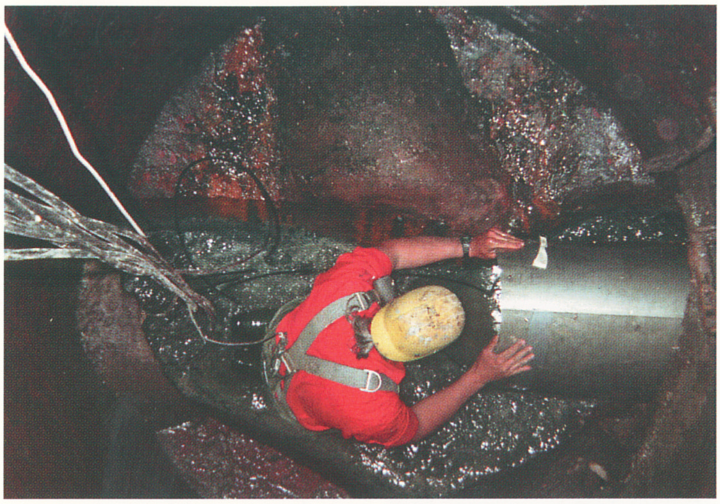
FAULT	ACTION
No digits on the 1408 display	Check fuses, replace any blown but contact Peek if replacement fuses blow immediately power is restored to the 1408. The three fuses on the power supply unit are: FS1 & FS2 - for mains input and should be rated at 250mA for 240V and 220V and 500mA for 110V operation. FS3 - for 12V supply to the 1408 boards, rated at 2A. MAINS powered - check supply is connected and ON. BATTERY powered - check battery is charged, if not replace with fully charged battery.
Flow Reading showing all 9s	Either no depth reading or no velocity readings.
Depth Reading showing all 9s	Ensure depth is below the programmed maximum depth value. INTEGRAL DEPTH Check there is enough water to operate the ultrasonic depth path. Check u/s depth path is not obstructed. Check transducer is still vertical. Check cable is intact and the covering insulator has not been damaged. Check the depth transducer is connected to the "Depth" BNC on the transducer board. EXTERNAL DEPTH Check the depth instrument output is connected to the Depth Input card and the Options carrier is connected to the digital board. Check depth instrument is working - see manufacturers manuals.

Velocity Reading showing all 9s	Check that the gauge is measuring the correct water level. Check there is enough water to operate the ultrasonic path(s). Check the u/s path is not obstructed. Check transducers are still aligned. Check the cables are intact and the covering insulator has not been damaged. Check the connections to the transducers. The "L" path should be connected to BNCs 1 and 2 and the "H" path to 3 and 4.

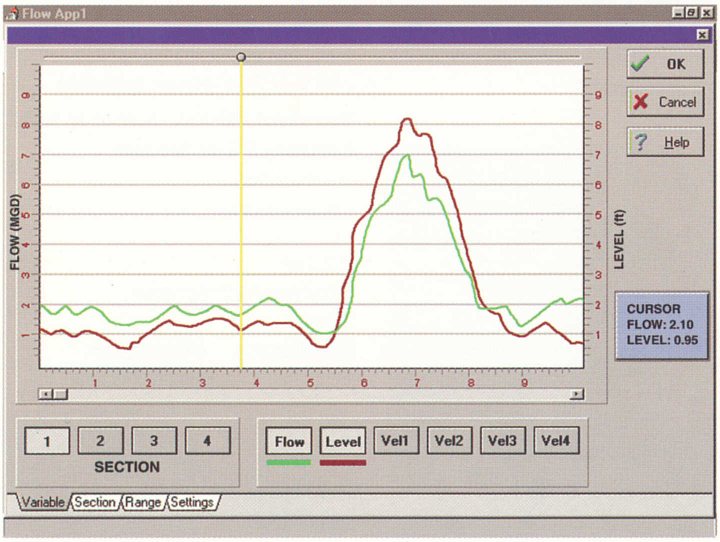
If the fault persists contact Peek Measurement.

FLOWMETER CONSOLE
MODEL 7510 MULTIPLE PIPE COMPOUND METER

Leaders in Acoustic Flow Measurement Systems



Sleeve installation in sewer. Transducers are pre-mounted on sleeve



Real-time data display

Windows® Interface

Accusonic Windows Interface allows the operator to easily configure the 7510 and retrieve data for display and analysis of current and historical data. Four modes are available: Setup Wizard, Site Commissioning, Real-Time Data Collection and Storage and On-Line Diagnostics.

System Description

The Accusonic Model 7510 transit-time flowmeter console is designed for accurate, reliable flow measurement in large pipes and open channels. In various configurations, the 7510 measures flow in pressurized pipes, open channels, and in pipes and conduits ranging from partially full to surcharged. The 7510 is ideal for measurement in collection systems, combined sewer overflows (CSO's) and treatment plants. One 7510 can be configured to measure flow in up to 4 pipes or channels.

When used as a 4 parallel-path or 8 crossed path flowmeter in full pipes, the 7510 measures flow to within ±0.5% of actual flowrate. Flow in pipes of 8 in. to 40 ft. in diameter can be measured economically with the system.

Transducers can be selected for a variety of applications, including:

- Exposed steel pipes
- Concrete pipes
- Buried or encased pipes
- Pipes with external access only
- Pipes that cannot be dewatered for installation
- Class I, Div 1 and 2, Group C and D locations

When used as an open channel flowmeter, the 7510 measures velocity at several depths and level (stage) in order to calculate flowrate. Velocity profile is measured by using multiple acoustic paths. Level measurement is input directly from a pressure or ultrasonic downlooking level sensor. Accuracy of flow measurement in open channels is typically within ±2.0% of actual flowrate using multiple paths. The system is designed to turn the acoustic paths on and off automatically as the water level in the channel rises above and falls below each path. The system also changes the integration method to account for the actual number of acoustic paths submerged and operating. The single path integration method computes flowrate based on a factor dependent on the relative depth of the path.

If appropriate, a Manning formula using water level input can be utilized when the level is below the lowest acoustic path. The system automatically changes its integration method if acoustic paths fail due to fouling or damage.

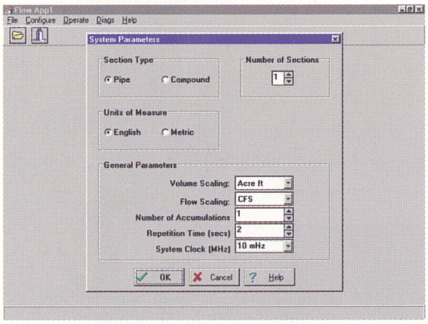
When the channel is surcharged the system changes its integration method to a full-pipe integration method used for pressurized pipes.

FLOWMETER CONSOLE
MODEL 7510 MULTIPLE PIPE COMPOUND METER

ACCUSONIC®

Leaders in Acoustic Flow Measurement Systems

Interceptor installation



System Parameters

Section Type

● Pipe ○ Compound

Number of Sections: 1

Units of Measure

● English ○ Metric

General Parameters

Volume Scaling: Acre ft

Flow Scaling: CFS

Number of Accumulations: 1

Repetition Time (secs): 2

System Clock (MHz): 10 mHz

System configuration screen

System Specifications

Power requirement
90-250 VAC 47-63 Hz
12-24 VDC

Enclosure
NEMA 4, 4X, IP65

Enclosure Dimensions
20" h x 20" w x 9" d (508 x 508 x 228 mm)
60 lb. (27 kg)

Measurement Options
Open Channel
Pipe Flowing Full
Pipe Flowing Partially Full to Surcharged

Output Options
4-20 mA (up to 4) non-isolated or isolated
Relay Contacts (up to 16) 10 A
110 VAC/0.5 A 110 DC
RS-232

Stage Input
4-20 mA (up to 4) 250 Ω input impedance
15 V or 24 V power available

Standard RS-232 Output to RTU, Portable PC or Modem
Travel times
Stage Levels
Path velocities
Volume
Flowrate (bidirectional)
Level
Diagnostics: signal gains
signal / noise
path status
system status
error type / location
Total Volume
Total Flow

Display/Parameter Entry Options
Via portable PC, Hand-Held keypad/display or remotely via an RTU

Number of Acoustic Paths
1 – 8

Number of Pipes or Channels
1 – 4
The total number of acoustic paths in all the pipes or channels can not exceed 8

Environmental Requirements
Storage:
0° to 150° F (18° to 65° C)
0% to 95% Relative Humidity
Operation:
15° to 140° F (-10° to 60° C)*
0% to 95% Relative Humidity

*Operational range can be increased with heater to:
-15° to 140° F (-25° to 60° C)

Power Consumption
26 Watts nominal

Data Logging
Optional internal data logger
selectable up to 90 days storage

Transducers

The Model 7510 can be operated with any of the Accusonic transducers. When the measurement location is in Class I, Division 1 or 2, Group C or D Hazardous areas, explosion-proof or intrinsically safe transducers must be used. Accusonic offers several explosion-proof and intrinsically safe transducer models which have been certified by FM and CSA for use in hazardous locations.

Data Verification and System Diagnostics

The Model 7510 has the capability to output raw data, including travel times and velocities to allow verification of data. Other operational checks ensure that the flowmeter is operating properly.

System Setup Using Windows®

Setup Wizard: The Setup Wizard is a simple step by step approach to configuring a flowmeter's parameters. The user is prompted through a series of menus that ensure completion of the parameter entry. The Setup Wizard is intended for the novice or infrequent user. Standard Windows® controls make the configuration process quick and easy.

Site commissioning: The 7510 for Windows® can be used to assist commissioning a site. As-built data can be compared to measured parameters to identify entry errors. Signal gains and status are used to verify alignment and positioning of the acoustic transducers.

Real-time data collection and storage: Real-time data can be collected and saved to hard disk for later analysis and reporting. The data can be displayed in several different formats to allow the user to compare flows, levels and velocities from different measurement sections. Data can be printed in graphical or tabular format and can also be copied to other Windows® programs.

On-line diagnostics: The application receives flowmeter status, self-test, and path gains to perform diagnostics that aid the user in troubleshooting problems. In addition, the acoustic waveform can be viewed for each acoustic path in the flowmeter to help identify the sources of error.

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ACCUSONIC®
Leaders in Acoustic Flow Measurement Systems

Ultrasonic Multipath Flow Metering

Technical Considerations

When choosing an ultrasonic 'time of flight' flow meter there are a number of technical features that determine the integrity, accuracy and reliability of the equipment and measurements derived from it - some of these are discussed below:-

Automatic Gain Controller

This allows the system amplifiers to vary their gains as the received signal strength fluctuates. A meter with AGC will be:-

1. far less susceptible to failure due to fluctuations in suspended solids.
2. capable of monitoring background noise and will not allow meter to be accidentally triggered by this.
3. not susceptible to errors due to amplitude modulation
4. less susceptible to failure due to temperature gradients
5. able to give an indication of suspended solids by variation in gain settings
6. capable of handling signal variations up to a factor of 50, compared to a factor of only 4 for a fixed gain system.
7. self configuring, requiring no initial manual set-up

Digital Signal Processor

Most modern flow meters now incorporate a digital signal processor to analyze the incoming acoustic signal, this has the following advantages over earlier designs:-

1. the system is able to distinguish between the acoustic signal and noise interference.
2. the signature of the required waveform is known to the flow meter, making it impossible for a false detection to occur due to noise.
3. the system can only give the correct flow or no flow, spurious results are not possible.
4. longer path lengths and higher levels of suspended solids can be handled.
5. higher levels of background noise can be tolerated
6. increases tolerance to density variations such as temperature gradients.

High voltage drive circuitry

The strength of the transmitted acoustic signal is partly determined by the voltage used to hit the piezo-electric crystal. The signal strength is a factor in defining the distance (path length) over which the system can operate and how well it performs in more difficult applications. Again continuity of data will be improved by higher drive voltages.

Calculation of accuracy of velocity measurement

In order to calculate the accuracy of the velocity measurement it is normal to compare the expected minimum time difference to the resolution of the clock within the signal detection circuitry, for example:-

Channel Width = 5m, Minimum velocity = 0.1m/s, Path angle = 45°

$$\text{Time difference} = \frac{2 \times W \times \cos\emptyset \times V}{C^2}$$

$$= \frac{2 \times 5 \times \cos 45 \times 0.1}{1500^2} = 3 \times 10^{-7}\ \text{Sec.}$$

$$\therefore \text{ Accuracy of system with 10mhz clock} = \frac{1 \times 10^{-7}}{3 \times 10^{-7}} \times 100 = 31.8\%$$

$$\therefore \text{ Accuracy of system with 100mhz clock} = \frac{1 \times 10^{-8}}{3 \times 10^{-7}} \times 100 = 3.18\%$$

Thus newer designs, which incorporate high speed digital electronics are a factor of 10 (TEN) more accurate than older systems just on the measurement of velocity.

Other factors such as depth, cross-sectional area, path angle, path length and number of transducers must also be taken into account when calculating overall flow accuracy.

Other accuracy considerations

- only a modern high speed system can maintain accuracy in a narrow channels (less than 5m wide).
- only a modern high speed system can maintain accuracy at low velocities
- only a modern digital system can work in wide rivers (~400m)
- a modern system will continue to operate in difficult applications where older designs 'drop out'

Flow Measurement at extreme shallow Water And very low Velocity

Wolfgang Stedtnitz
Stedtnitz Maritime Technology Ltd.
Eganville, Ontario , Canada.

Abstract - **Acoustic flowmeter are bound to certain minimum depth limits to allow to distinguish between direct signal and reflected signals from the surface and the bottom. If these restrictions are not obeyed the measured velocity will bounce around and unreliable data will be the result.**

To overcome the problem, guiding blinds were used to deflect the unwanted reflections. Reliable operation could be obtained down to the limit where the transducers became just wet.

We report about three projects; the first site is in Texas to control an irrigation channel, the second is located in the Everglades, west of Alligator Alley in Florida with velocities as low as 1 mm/s. Continuous measurement must be maintained over a long time period, because this is a critical parameter to monitor the biological studies at the site. The third is one of our test sites with velocities between 1 mm/s and 6 mm/s. Test results from the AFFRA and the DELTAFEX are presented, which show high velocity resolution as well as almost zero offset.

I. INTRODUCTION

A. The Shallow Water Problem

ISO 6418 sets rules for the minimum distances between the acoustic path of an AVM and the surface as well as to the bottom. The distances are required to provide sufficient delay time between the direct path and the reflected path. The minimum delay usually is 1.5 wavelengths, but for safety reasons and to allow moderate ray bending the delay should be better 3 wavelengths to assure reliable operation.

Often the situation in the river or creek demands operation in shallower water and the above mentioned rules cannot be met. What can be done?

B. The Low Velocity problem, Resolution and Offset as function of the path-length

AVM's measure the differences of transit-times in both directions between the horizontally looking transducers. Counting crystal controlled clock-pulses in a so-called start-stop mode does the time measurement. A gate opens coinciding with the transmission pulse and closes with the arrival of the signal received at the opposite transducer. The higher the frequency of the clock is, the better is the timing resolution. Moreover, unavoidable internal delays of the signals received from both directions must match precisely within a few nanoseconds; otherwise a systematic velocity offset will be produced. This is only possible if both directions use physically the same electronic devices, the same transducers, transmitters and the same receiver. Any switching device may not introduce additional time delays.

The measured transit times become proportionally shorter with decreasing pathlength. Therefore resolution and offset become more critical with shorter pathlength, because the quantization error is rising.

The AFFRA goes a step further and uses an averaging technique to achieve one order better resolution than what would be possible with a 16 MHz master clock. Thus 1mm/s resolution and repeatability is achieved with 10 m pathlength.

II. TECHNICAL SOLUTIONS

A. Use of Deflectors

In a creek near Eagle Lake, Texas an acoustic flowmeter AFFRA was to be used, but under conservative view the installation was impossible, because at least temporarily the water level is too shallow. The second problem we were facing was that the water level was supposed to change between 0.3 m and 3.5m within minutes. For this reason a two-path system seemed to be necessary. This had two consequences:

The lower path had to be installed at a depth where bottom reflections would severely interfere with the direct travelling pulse and flawed velocity measurement could be predicted. Surface reflections would occur at least as long as a shallow water situation would persist.

The upper path should be installed at optimum depth to measure at mean water level. This means that the upper path would be troubled by surface reflections at least at certain critical water levels. Moreover the upper path could fall dry over quite a period of time.

To overcome the above mentioned problems for the first time a blind was installed with two purposes:

1. to block the bottom reflections for both path completely
2. to block the surface reflections for the lower path completely and for the upper path as long as the surface reflection could interfere. Beyond that stage reflection is allowed to use the feature of the DELTAFLEX to measure the velocity close to the surface.

The first attempt with a blind in the middle of the river failed in so far that interference was experienced at specific depths with both paths, both at different water levels. The lower path was never completely stable, the upper path stabilized with higher water level.

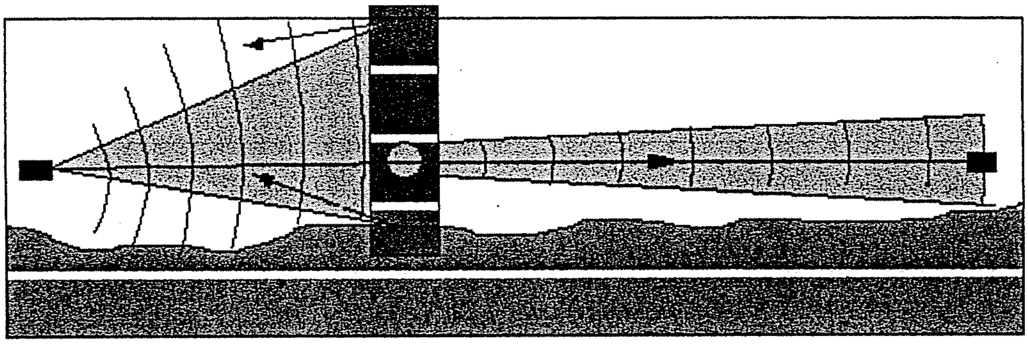
The first design was approached on the basic view that the lower path transmission pulse would run only along the center of the main beam of the transducer through the lower aperture and the upper path transmission pulse through the upper aperture of the blind. During the test run at the site by accident cable-connections were swapped and one upper transducer communicated with one lower transducer. With optical geometry in mind this should be impossible. Not so with acoustical waves. A gain was measured which was as high as if the blind would not exist at all. This leads to the insight that wave theory must be applied which takes into account that refraction takes place at any aperture, that of the transducers and of the blind.

A new design had to be found with the following criteria's:

> All refracted or reflected signals must be delayed by at least 3 wavelengths. The wavelength is 7.5mm which corresponds to 15 microseconds travel-time
>
> The bottom reflection must be deflected such that the signal cannot reach any opposite transducer
>
> Existing positions of transducers shall be maintained

The transducer theory says that the beamwidth is reverse proportional to the diameter of the aperture. The aperture of the transducer is chosen to make alignment as easy as possible, at the same time realizing that even a pencil beam transducer cannot avoid bottom or surface reflections. The suppression of reflections must be accomplished completely by delaying the reflected signals and by making the pulse length as short as possible to minimize the necessary delay as much as possible.

Aperture Windows for Very Shallow Water

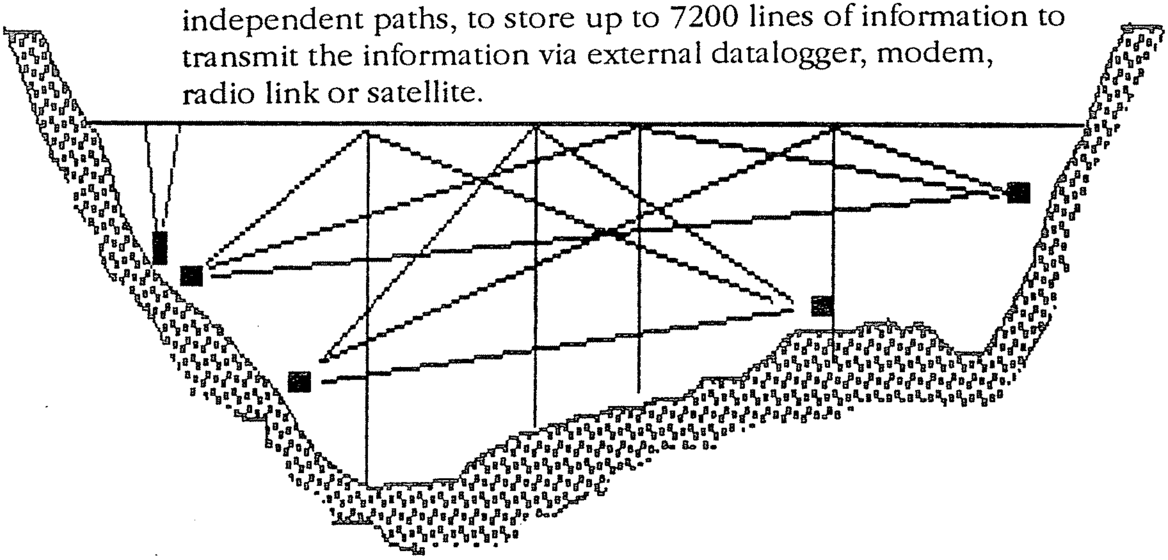


1. The unwanted reflections at the surface and at the bottom are deflected
2. The section of the beam, which passes the aperture has a much narrower beam thus avoiding secondary reflections
3. The alignment is easy and not at all critical

△ **DELTAFLEX** Stedtnitz Maritime Technology

Multiple Pseudo Double Path Acoustic Flowmeter

Complete self-contained Data Aquisition System to measure velocity, water level, temperature and discharge with up to 4 independent paths, to store up to 7200 lines of information to transmit the information via external datalogger, modem, radio link or satellite.



TWO WAY VELOCITY MEASUREMENT ALONG THE DELTA PATH
- one direct and one reflected at the surface -

AUTOMATIC CORRECTION OF K - FACTORS WITH CHANGING WATER LEVEL

INTEGRATED ACCURATE WATER LEVEL MEASUREMENT

INTEGRATED TEMPERATURE MEASUREMENT

INSTANT SDI-12 READINGS (WITHIN 6 SECONDS)

SDI-12 AVERAGE READINGS WITHOUT WAITING TIME

AVERAGES CALCULATED FROM 1 MINUTE BACKGROUND SAMPLES

AUTOMATIC PATHLENGTH DETECTION

Simple, fast and non-expensive installation

Accuracy +/- 2% for velocity, +/- 5% for total discharge, +/- 1/100" for water level over full temperature and salinity range

Zero velocity capability with changing sign if flow reverses, resolution 0.003 ft./s

Wide range from 30 to 1300 ft path length with one model

Lightning protected system if installed according to manual with MTBF >50 000 h tested in High Voltage Lab

Automatic k-factor correction to calculate discharge on-line

SDI-12 compatible interface supporting all standard commands

RS232 interface to set parameters via laptop computer
Adjustable Baudrate

Low power consumption (12V, 200 mA operating, 8 mA sleep mode) Average Power consumption <200 mW

Portable rugged, watertight enclosure 4.3" x 4.3" x 8.6", all MIL type connectors
Wide temperature range from -40°C to +85°C

Supporting GAP software to manage and load parameters

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UNITED KINGDOM
FAX: (01727) 827838
TEL: (01727) 827837

TECHNICAL SPECIFICATIONS

Size: 230 x 110 x 110 mm / 9 ¼ x 4¼ x 4¼"

Weight: Approx. 2.6 kg / 6 lbs.

Power Comsumption: 2 W at 12 V, 100 mW in sleep mode

Time to measure one sample, containing 4 independent measurements, every minute: typ. 6 seconds

Separate SDI-12 commands for each path and for instant and average data over specified time selectable

Operating temperature: - 40°C to +85°C; -40°F to +160°F

Interfaces: RS232C and SDI-12

Path length: 10 to 400 m; 30 to 1200 ft.
shorter path length on request

Transducer dimensions: 2" diameter, 2" long
plus 1½ shaft

Transducer weight: 1 kg / 2 lbs.

Beam width: +/- 10°

Standard cable length: 10 m; 30 ft.

max. total cable length including splices: up to 3000 ft.

Output format: Metric or American Standard

CE approved

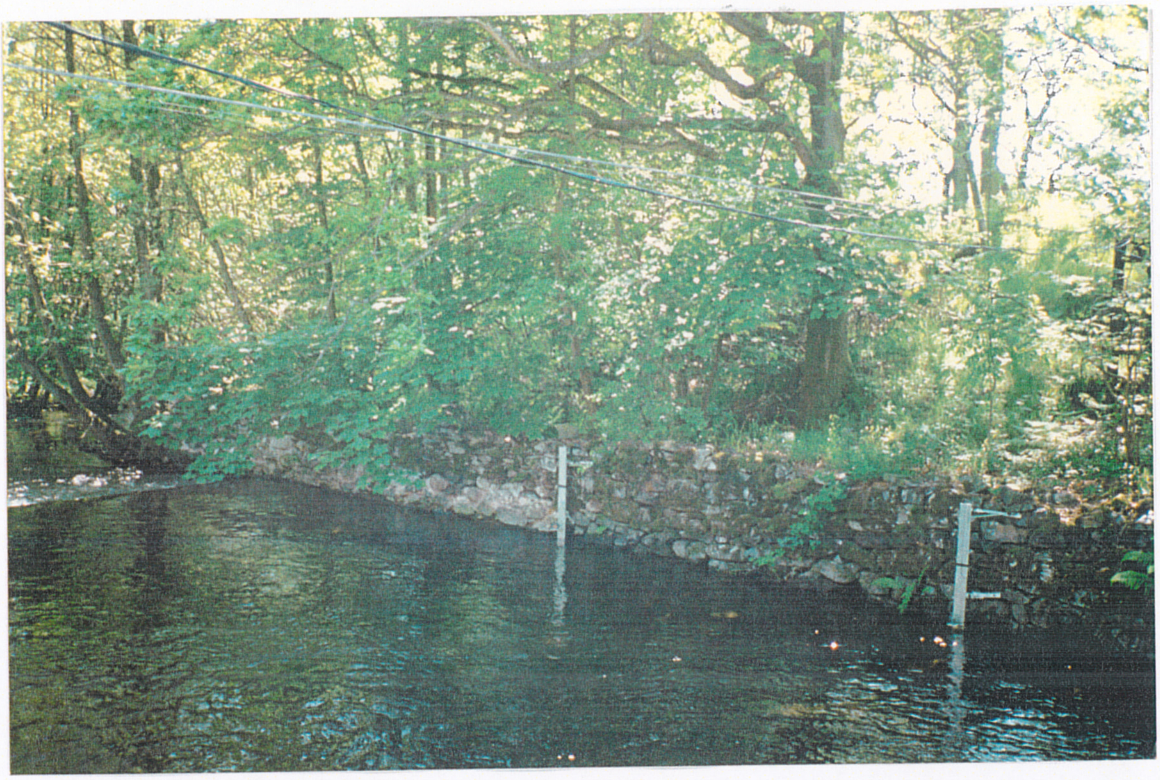
Looking upstream over the weir at Walcot on the River Tern

View downstream and across to the Walcot gauging station and weir from the upstream transducer rack, visible in the immediate foreground.

Close up of upstream transducer rack at Middleton in Teesdale

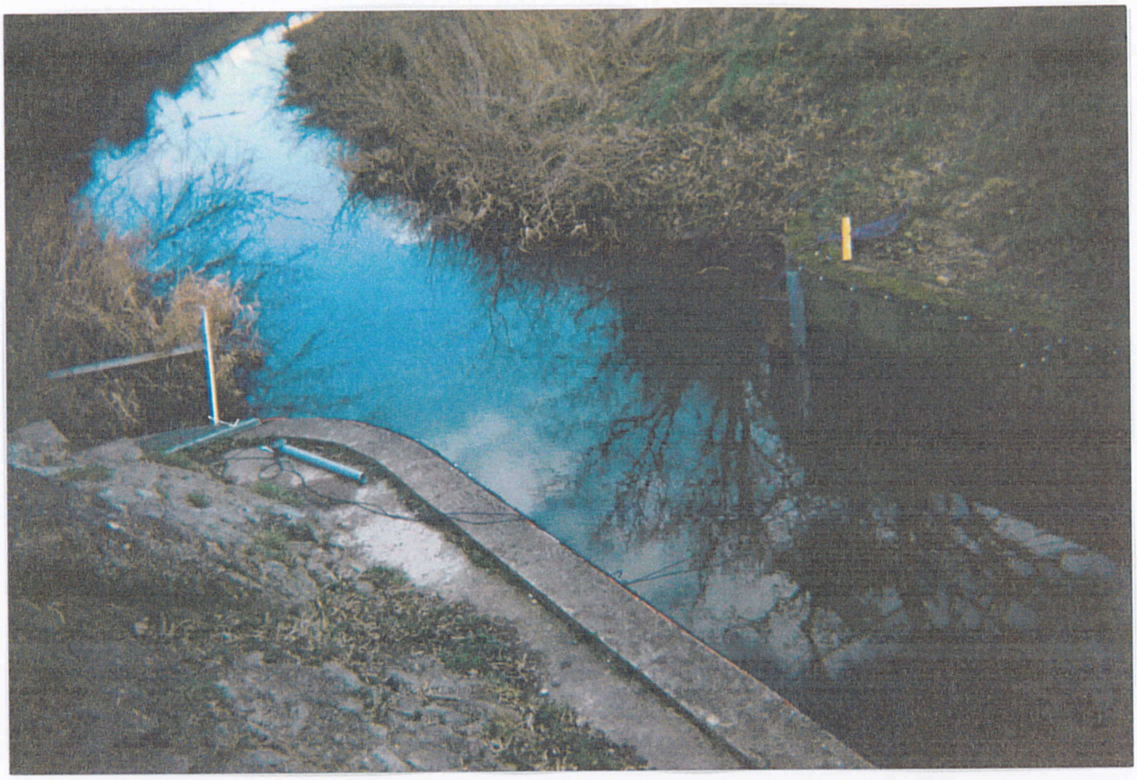
Middleton in Teesdale upstream transducer rack under high flow conditions

Middleton in Teesdale - view taken looking downstream to weir (top) with transducer rack on far bank just visible, and looking upstream over the weir crest from the far bank (lower).



Low Nibthwaite - view downstream to far bank showing transducer racks and weir.

Low Nibthwaite - view upstream to near bank showing the two transducer racks together with the depth mounted in the stilling tube.



Two views of the channel at Lea Hall with the reflector trials underway

Two views of Lea Hall gauging station with the Aldford Brook fully backed up

Looking across to the Greenholme station hut along the line of the velocity paths. Transducer racks can be seen in the immediate foreground (downstream) and on the far bank (upstream).

Looking across the River Irthing at Greenholme from the gauging station to the downstream transducer rack under low flow conditions.

Blackford Bridge weir under low flow conditions

Blackford Bridge weir and channel under high flow conditions

Blackford Bridge weir under low flow conditions

Blackford Bridge weir and channel under high flow conditions

Looking across to the Greenholme station hut along the line of the velocity paths. Transducer racks can be seen in the immediate foreground (downstream) and on the far bank (upstream).

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Middleton in Teesdale upstream transducer rack under high flow conditions

Looking upstream over the weir at Walcot on the River Tern

View downstream and across to the Walcot gauging station and weir from the upstream transducer rack, visible in the immediate foreground.