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Gauging of Rapidly Varying Flows in Urban Streams

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SUMMARY: Stream water quality is now a major issue world wide. Politicians recognise the implications of the problem and are considering both remedial and preventative measures to address the situation. However, the determination of water quality within an urban drainage system and hence the impact of the stormwater on the receiving water depends on an accurate assessment of the water quality. A major source of error in the determination of flow quantity has been recognised as the time required to physically gauge streams and drains in flood. The standard accepted method of gauging uses a simple average of the gauge heights at the start and end of the time period over which measurements across the entire section are taken. Past experience dictates that this method should only be applied with confidence to steady gradually varying flow situations which are associated usually with large streams and rivers.

A perusal of flood hydrographs for streams with high rates of rise and fall will indicate the variability of the water level over short periods of time. Typically the level can fluctuate in both directions several times during the time taken to complete a standard gauging. This makes any simple averaging of the gauge height almost meaningless and does not reflect the conditions that may have applied at any sub-section when its measurement was taken. An alternative method for use in these circumstances involves the monitoring of the gauge height for each sub-section while the velocity of that sub-section is determined. This then allows more time and care to be taken with each individual measurement which in turn reduces the inherent errors identified in the standard method. This paper presents an outline of this alternative method and discusses its application for gauging rapidly varying discharges in small rural streams and urban drainage systems.

THE MAIN POINTS OF THIS PAPER

- A major source of error has been identified in the standard discharge measurement procedures at sites that are prone to experience rapid rates of change in water level.
- The actual time required to physically gauge those unsteady sites compounds the error.
- The described method produces an accurate assessment of discharge and any anomalies are readily identifiable in the graphical results.

1. INTRODUCTION

Chemists are constantly striving to devise the ‘best’ methodology for precise determination of the actual quality of our waterways to enable appropriate remedial measures to be planned and implemented as well being a legal requirement. It is therefore essential that we all participate in this quest for precision by refining our appropriate methodologies.

It is a well recognised fact that the determination of water quality in a stream depends (apart from the chemical aspect) on an accurate assessment of the quantity of the water present. The standard velocity-area method of gauging has been described in detail by numerous authors, some with variation and refinement. The method described in this paper is another refinement for a specific application.

2. BRIEF DESCRIPTION OF THE STANDARD VELOCITY-AREA METHOD PROCEDURE FOR STREAM GAUGING.

The application of current metering for development of a rating curve at a gauging station site (a location where water surface level is recorded) is referred to as stream gauging.

Details of the U.S. Geological Survey Standard Procedures are outlined by Rantz (1982). Many other authorities have similar procedures but have only documented these procedures in a form for internal use.

The following discussion summarises the stream gauging procedure outlined by Rantz (1982). The procedure is:

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⇒ A marked line is stretched across the channel and the flow depth is measured at regular intervals. This provides information about the cross section through which the flow is occurring and, in particular, information about the cross sectional area.

⇒ Current meter recordings are made midway between each depth measurement at the relevant number of points. This will result in an estimate of the depth averaged velocity between the depth measurements.

⇒ The total discharge is computed from the sum of the individual section discharges.

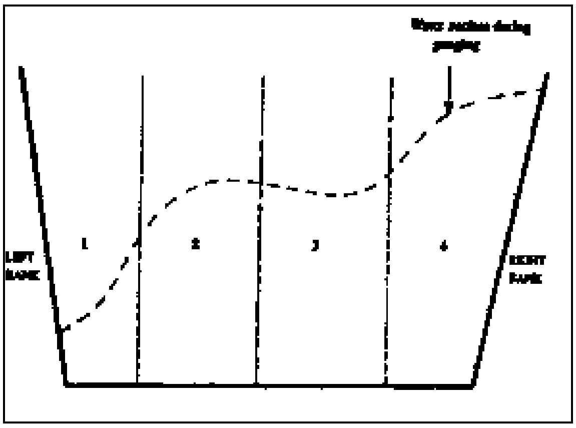

Figure 1: Schematic Representation of a Stream Cross Section for Gauging Purposes

Referring to **Fig. 1**, and in relation to the standard method, each vertical line represents the boundary of a section and the depth is determined at each one (can be many more sections - 10 is common). The method also requires velocity measurements to be obtained in the mid section between vertical boundary's at more than one depth in that mid section (depth dependent).

The standard method requires that a gauging commences on one stream bank (left or right looking downstream) and finishes at the other bank. The water level or gauge height is obtained immediately before and after the gauging. When there is a variation in the gauge height an average gauge height is commonly calculated.

Errors occur when the water level changes rapidly as suggested in **Fig. 1** and an average calculation may not indicate the true gauge height at the time of the velocity determination. The proposed method is time and gauge height based which enables a composite collection of data for later dissemination and reveals a more accurate data set.

Figure 2 : A dry Powells Ck. urban stormwater channel at Strathfield

3. RAPIDLY VARYING FLOW SITES

Both small rural and urban catchments have been long recognised as being difficult to gauge during flood events (Pilgrim & Cornish 1974). A major problem associated with the gauging of many small catchments is their common characteristic of fast response times, very rapid rates of rise and fall in stage level often accompanied by extreme stream flow velocities. Rise rates approaching 13m per hour have been reported (Tilley & Doran 1982 at Strathfield) and velocity readings in excess of 6m per second have been observed at the same site (Tilley & Doran 1990). The rise rate and the high velocity combine to make an extremely dangerous and physically demanding work environment. See **Fig. 2** and **Fig. 3**. The urban situation is further exacerbated by the very high percentage of impervious areas in the catchment such as roads, footpaths, car parks, roofs etc. Impervious areas generate larger discharges and higher fluctuations of flow levels by preventing excess rainfall from infiltrating into those surfaces which decreases drainage times and increases velocities.

Figure 3 : Strathfield Drain during an event.

Another difficulty encountered relates to the actual time taken to gather sufficient relevant and reliable data to enable an accurate addition to the discharge rating table. Using the proposed method, much of this extra time can now be eliminated.

4. DISCHARGE MEASUREMENT ERRORS

A major source of error in the traditional standard velocity-area method for gauging has been recognised as being contained in the actual time required to physically gauge unsteady streams when in flood. At these sites the traditional method can become very time consuming relative to the amount of time available to adequately gauge the discharge. In an attempt to reduce that time certain compromises are often made that effect the overall quality of the gauging. For example the number of sub-sections for velocity measurement are usually reduced to the barest minimum, the number of vertical section velocity points are often reduced to one and the sample time for that velocity is also reduced to below the recommended minimum. These all contravene the acceptable standards for flow measurement in open channels. Individually they can add a substantial amount of error to the subsequent result, however, when combined serious doubts must be placed on the validity of the data set. It is unfortunate that these ‘shortcuts’ are often deemed as necessary to obtain the maximum benefit of a flood stage situation. This may be done in the belief that any measurement is better than none when trying to gather data under difficult circumstances to extend a rating table.

As well as the above the ‘standard method’ usually encompasses an averaging of the gauge height over the time taken to complete the gauging. While this works well for larger steady streams and rivers the same does not apply to the unsteady ‘rapid rate’ sites. At these latter sites there exists the possibility of several large fluctuations in water level in both directions in the relatively short period of time taken to complete a conventional gauging.

The amount of turbulence combined with the extreme velocities often found in these situations can also contribute to the overall error.

5. METHODOLOGY

The possibility exists to alter the conventional approach to gauging, at unsteady sites, with a method that saves time and perhaps gives a more meaningful result. The proposed method produces an accurate assessment of discharge and any anomalies can be readily identified in the graphical results. See **Figure 4** for an example.

Two previous papers (Tilley and Doran 1990) and (Tilley et al 1996), and an early ISO Standard for tidal flow measurements (I.S.O. 2425. 1974) described the method. As discussed by Tilley and Doran (1990), shown in **Fig. 5** is an ideal schematic cross-section for the continuous gauging method. The diagram illustrates a gauging site with four sub-sections. A dashed line indicates the water surface level during a typical gauging. With this example, measurement would proceed continuously by sampling velocity and water depth at each sub-section from the left bank to the right bank, back to the left bank and so on, as indicated by the arrows and dashed line.

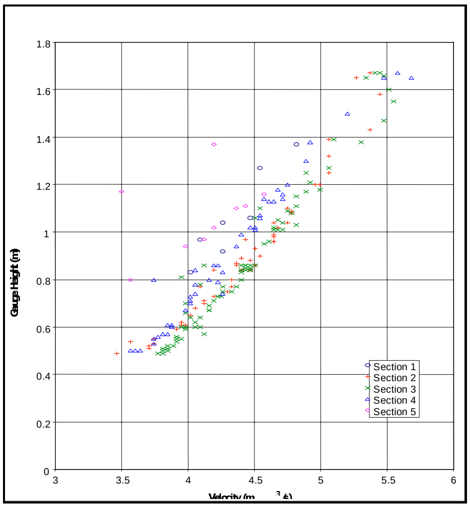

Figure 4 is a graph of the gauge height Vs all of the sub-section velocities

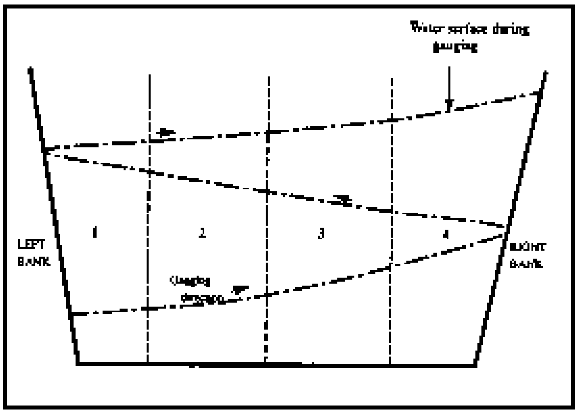

Figure 5 : Schematic Cross-Section for the Continuous Gauging Method (after Tilley and Doran 1990)

6. FIELD PREPARATION

Of paramount importance is the location of a ‘suitable’ site. The basic requirements are the same for both the standard and proposed methods i.e.- the usual straight section, even flow etc. The major diversion from the conventional method is in the requirement for a stable, well defined measuring site that exhibits a static relationship between the gauge height and the water depth at each sub-section. Close proximity (within reading distance if possible) of the staff gauges is also desirable. When a suitable site is chosen it must then be accurately surveyed to determine the precise sub-section areas and velocity observation site depths. The cross section needs permanent marks or easy reference points established to enable repeatability of measurements from the same locations. The reference points can range from marks on a bridge railing, distance from a permanent reference point etc.

Referring to **Figure 5**, and starting at, say, the left bank the order in which the sub-section velocity observations could be taken are - 1234321234…. or 123443211234…. or 12341234…. The first method is probably the most efficient with respect to time for gathering data because the observation locations are continually moving back and forth across the stream.

At the Strathfield Drain site a light steel "I" beam was fabricated and permanently marked with measurement locations. This was then easily placed and locked into position across the channel, when required, with precision. **Figure 6** shows a schematic of the cross-section divided into measuring sub-sections.

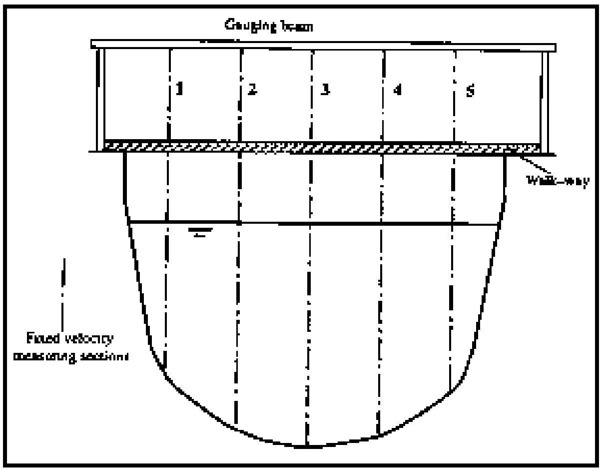

Figure 6 : Schematic Representation of Strathfield Drain Cross-section Sub-sections

6.1 Field Measurement

The equipment required is virtually the same as for the conventional method, the only additional item required being a watch or clock to obtain the time of each observation. Each velocity observation recording must consist of the location in the cross section, the gauge height and the current meter reading. To obtain a time series relationship for gauge height, areas, and discharge the actual time each observation was taken must also be recorded.

As in a normal conventional gauging a minimum of two people are required, one to operate the current meter while the other reads and records both the gauge or reference height as well as the actual time of each observation, for every observation. With practice, at a site that only has 1 or 2 metres between observation points, using a standard velocity observation time and with the need for continually obtaining depth readings eliminated, it is possible obtain one velocity reading per minute. This rate of recording can be maintained indefinitely or until physical exhaustion takes over!

The data set collected in this way can follow a combination of rising and falling hydrograph limbs. Not only does this add valuable rating data to the data set, it can also assist into the investigation of rising and falling stage discharge relationships i.e. Loop ratings.

6.2 Field Recording

At sites with a stable bed the field booking sheet generally becomes a lot less cluttered and only requires four columns i.e. :-
Section No. = Distance from a reference point,
Time hours = Individual observation time,
Gauge height = Water level or depth reference,
Meter revolutions = Actual current meter pulses.

See **Appendix 1** for a gauging form example designed for the method at UNSW.

Other columns have been added to this form to compliment the data set collection i.e.:-

- Meter depth - surface, 0.6D, actual depth etc.,
- Revs / second is for a conversion of the fan revs to the format of the current meter table i.e. revolutions in 45 seconds to revolutions/second,
- Velocity m/s - current meter rating velocity,
- Remarks - i.e. debris fouling meter fan etc.

7. COMPUTATIONAL PROCEDURE.

The computational procedure is actually a graphical technique. The current meter readings are converted to velocities and the survey data is converted to sub-section areas linked to the gauge height range. The data is then inserted into a computer spreadsheet format such as Excel. Once in such a form it is then a simple matter of rearranging or sorting the data into order such as Section No., Gauge Height and Time.
The required data sets can then be extracted for the establishment of a graphical relationship of the sub-sections in such areas as gauge height vs. area, discharge, velocity and time which then allows the totals to be extracted. At this stage, any erroneous parameter readings are readily identifiable on the graphical plot. These can then be investigated and corrected or removed from the data set altogether.

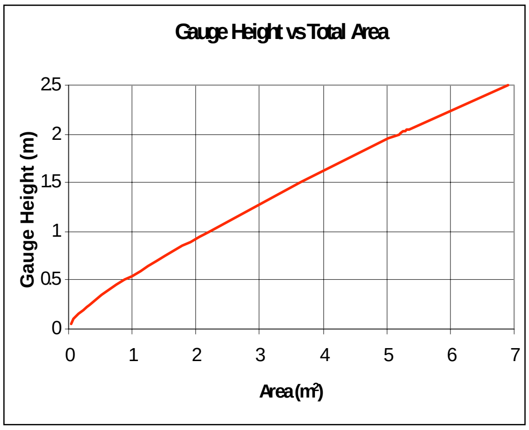

Figure 7: shows gauge height vs. total cross-sectional area for Strathfield

8. APPLICATION OF TECHNIQUE

The proposed technique has been applied to two gauging stations operated by the UNSW in Sydney. A full description of its application to one site follows; the application to the second site was similar and is described by Abustan (1998).

The Strathfield urban stormwater drain has a catchment area of 231ha and includes much of the inner western Sydney suburb of Strathfield. Most of the catchment is residential and includes several private schools as well as the main Strathfield Plaza shopping area. The gauging station is located in an open 'U' shaped concrete lined channel 2.5m deep and 3m wide. The station is about 25 m downstream from the confluence of two underground pipe networks. **Figure 6** is a sketch of the cross section including the gauging beam and walkway. Site preparation consisted of a steel pipe fabricated walkway that was installed over the channel when required. A light steel "I" beam fitted on the upstream side to rest the current meter winch board on. This beam also had permanent location marks on it for observation points.

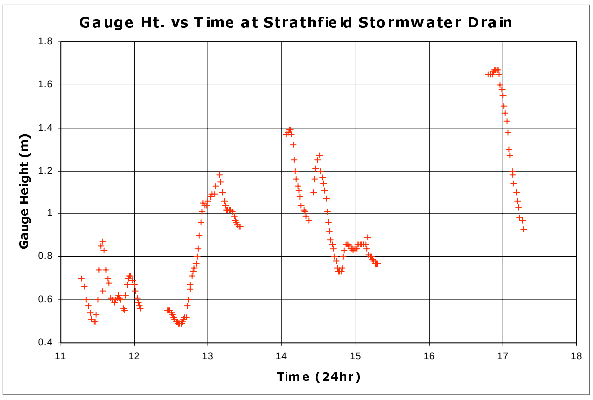

Figure 8 : Gauge height Vs time for six hour gauging period at Strathfield

Following are graphical examples of the data compiled from Strathfield:

Figure 8 shows a time series of gauge height vs. actual time where each data point represents one velocity observation - 188 of them taken in approximately 3 hours over a 6 hour period. Depicting the actual hydrograph as the gauging was being carried out.

Figure 4 is a graph of the gauge height Vs all of the sub-section velocities. Anomalous data points can be plainly seen in all five of the sub-sections. Some of the data points were so obviously outside of the normal range of the set that they were noticed in the field and marked accordingly. Some further investigation was required to decide which of the above outlying points were to be discarded so as not to corrupt the data set.

Figure 7 shows gauge height vs. total cross-sectional area. This was taken from survey data and entered into the spreadsheet for each sub-section. The resulting table was used for discharge calculation lookups.

The sub-section data were also plotted on a log-log scale, and linear regression analysis performed on each (minimum R^2 value 0.998). The resulting equations for the lines were used to construct a rating table for the entire drain. See **Figure 9** which shows the rating table for the entire drain that was constructed from the resultant equations.

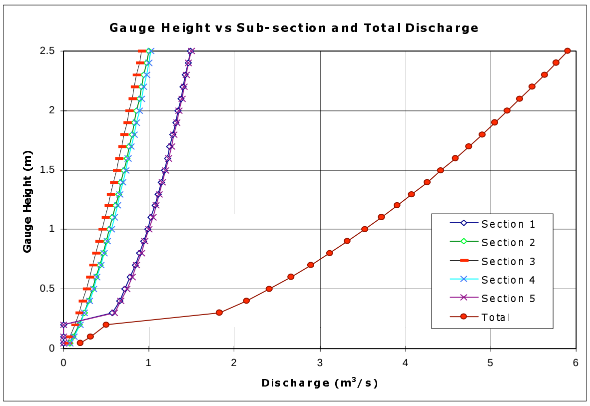

Figure 9 : Rating table constructed from equations for Strathfield Drain

9. COMPARISON OF TECHNIQUES

Using the Strathfield hydrograph as an example and looking at **Figure 5**, if a conventional gauging was commenced at 1251 hours, gauge height 0.8m and completed at 1326 hours, gauge height 0.94m would the 'average' gauge height be 0.94 + 0.8 / 2 = 0.87m? What of the peak of 1.18m at 1309hrs - would the discharge fit the rating curve?

When a data set is plotted in this manner it is very easy to detect, at several stages of the process, if any of the data points lay outside of acceptable bounds. These may be caused by human error - incorrectly read or booked in the field, or machine error - especially if the current meter was influenced in some way etc. Those points can then be further investigated and a decision made as to whether they should be excluded from the data set altogether as being a corrupting influence on an otherwise good data set. This graphical technique quickly highlights points which should be investigated further.

10. CONCLUSION

Larger streams and rivers, even in flood, generally do not exhibit rapid rates of rise and fall so a simple averaging of gauge height may normally suffice. However, all larger streams and rivers start from small beginnings. It is the combination of those small streams and drains that are of concern and the described method offers an alternative to the ‘standard’ method by providing a more precise measurement for the establishment of their rating curves. Human and equipment measurement errors are easy to identify. Since this method is basically a graphical one, any velocity deviations are readily identified and can be investigated and removed if required. This corrects the velocity curve before calculations are undertaken to produce the station rating curve.

The continuous readings of all sections provide more reliable data. By having the sub-section velocities and relevant gauge heights measured continuously, the actual discharge can be related with greater accuracy to the gauge height.

11. ACKNOWLEDGEMENTS

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12. REFERENCES

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13. APPENDIX 1

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Continuous Gauging Sheet

Method Devised by D G Doran

<table>
<tr><td colspan="2">Date: / /</td><td colspan="4">Station:</td><td colspan="2">Section:</td></tr>
<tr><td colspan="2">Meter:</td><td colspan="2">Fan:</td><td colspan="2">Observers:</td><td colspan="2">Sheet: Sheets:</td></tr>
<tr><td>Section No.</td><td>Time hrs</td><td>Gauge Height</td><td>Meter Depth</td><td>Meter Revs</td><td>Revs/ Second</td><td>Velocity m/s</td><td>Remarks</td></tr>
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