Streambed longitudinal gradient and unit stream power analysis of tributary streams of North East Victoria, Australia

R. E. Hardie*

ABSTRACT

This paper provides a review of surveyed streambed gradient information for 41 reaches of tributary streams in north east Victoria. The purpose of the review is to explore the data set of survey information and assist waterway managers with the identification of streambed longitudinal gradients for the design of streambed stabilisation works. Wide variability in the streambed gradients found limit the applicability of the results as a deterministic tool. However the information presented provides an indication of the typical streambed gradients and estimated unit stream power encountered for a number of streams in north east Victoria.

1. INTRODUCTION

Streambed and bank erosion have been identified as major issues in north east Victoria. This region includes the catchments of the Goulburn, Broken, Ovens, Kiewa, and Upper Murray Rivers (refer figure 1). The extent of streambed instability problems in the region have been described in the North East Region Landcare Plan (Anon, 1993) and in reports by I. N. Drummond and Assoc. Pty Ltd. (1984a, 1984b, 1984c, 1984d) and reports by Ian Drummond and Associates Pty. Ltd. (1986, 1988, 1989, 1990). According to these reports streambed instabilities including channel incision are present in streams throughout north east Victoria. The factors influencing channel incision in a number of streams of north east Victoria have been described by Rutherfurd (1993), Sherrard (1990) and Erskine et al (1993). According to Ian Drummond and Assoc. Pty. Ltd. et al (1988) the streambed incision is resulting in the loss of public and private assets such as roads, bridges, pump sites, fencing and agricultural land. Further, the sediment derived from the incision is contributing to downstream reductions in stream environmental conditions and reductions in channel capacity, leading to waterlogging of soils, and increased overbank flow .

Streambed stabilisation works are currently being undertaken through the region by landcare groups and waterway management authorities to arrest headward erosion and reduce sedimentation of waterways (Ian Drummond & Associates 1991, Anon 1993, Ian Drummond and Associates 1984).

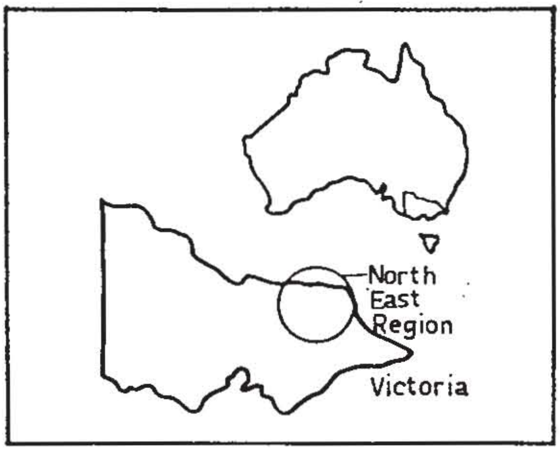

Figure 1 North East Victoria Australia

According to the Standing Committee on Rivers and Catchments (1991) grade control structures are an appropriate means of achieving streambed stabilisation. According to the Standing Committee on Rivers and Catchments (1991) the location and sizing of grade control structures should be based on the selection of a design streambed longitudinal gradient identified from either an adjoining stable channel reach or from channel velocity and tractive force analysis.

This paper provides streambed longitudinal gradient information for 41 stream reaches surveyed by waterway management authorities and landcare groups in north east Victoria. The information has been reviewed to explore relationships that may assist with the design of streambed stabilisation works.

2. SURVEYED STREAMBED LONGITUDINAL PROFILES

Streambed longitudinal profile surveys have been undertaken on streams through north east Victoria and elsewhere to assist the identification of streambed instabilities, and to assist identification of longitudinal streambed gradients for the design of streambed stabilisation works. The surveys used for this investigation were undertaken between 1988 and 1993 (Hardie 1993). A total of 41 surveyed stream reaches have been included in this investigation. The surveys were undertaken by waterway management authorities and landcare groups operating in the north east Victoria. The surveys were undertaken using standard level

---

* I.D. & A. Pty Ltd, PO Box 165, WANGARATTA VIC 3676
Telephone: (057) 22 3300 Fax: (057) 21 9433

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

survey procedures. Equipment included an automatic level, survey staff and distance measuring wheel. The surveys were typically undertaken by a field party of two persons. Bench marks and reference marks were installed during surveys to assist the set out of grade control structures. Typically the surveys were tied into the Australian Height Datum (AHD). The surveys identified the bed of the stream including any irregularities including nick points, headcuts, pools and riffles. Stream cross sections were available for 24 of the 41 stream reaches reviewed.

3. IDENTIFICATION OF DESIGN STREAMBED LONGITUDINAL GRADIENT FROM STREAMBED SURVEY INFORMATION

Two methods of identifying the design streambed longitudinal gradient from the streambed survey information have been assessed. Both methods require the identification of the streambed gradient in a relatively stable reach of channel in the vicinity of the subject reach between major bed inconsistencies such as rock bars or headcuts.

3.1 Graphical method

A graphical method was used to identify the design streambed longitudinal gradients from the streambed survey information for the 41 stream reaches. The method comprises the following:

1. Project a straight line through the pools or low points of a section of stream reach between major nick points and head cuts.
2. Calculate the gradient of the line from the survey information
3. Repeat 1 and 2 above for a section of stream reach adjacent to that previously assessed
4. Compare calculated gradients and estimate the design streambed longitudinal gradient for the subject reach of stream.

3.2 Regression analysis method

The graphical technique has been compared with the use of a spreadsheet package to identify the streambed longitudinal gradient. Using regression analysis for streambed gradient data the streambed profile can be assessed for various sections of a stream reach. The estimated streambed gradients for Hodgsons Creek near Tarrawingee and lower Boggy Creek near Moyhu using the two techniques are detailed in the Table 1.

Table 1 Hodgsons Creek and Lower Boggy Creek streambed longitudinal gradient analysis.

Stream Reach	Streambed gradient by graphical method	Streambed gradient by regression analysis
Hodgsons Creek Ch2500	0.0036	0.0035
Hodgsons Creek Ch5000	0.0023	0.0023
Boggy Creek	0.0007	0.0008

For Hodgsons Creek and Boggy Creek the streambed longitudinal gradients estimated using the graphical method are similar to the estimated profiles using regression analysis. Although the limited extent of this comparison prevents any conclusive finding, the graphical method of stream profile identification used for this analysis appears to provide a satisfactory estimate of the representative streambed gradient between major nick points and headcuts.

4. DATA ANALYSIS

Lane (1957) identified streambed longitudinal gradients to be a function of sediment size, sediment load, and streamflow, other factors impacting on streambed longitudinal gradient include channel geometry, meander patterns and channel roughness.

4.1 Catchment area analysis

Hack (1957) developed a relationship between stream channel geometry and catchment area. Willgoose, et al (1991) and Tarbotton, et al (1989) have developed relationships between streambed longitudinal gradients and catchment area. The stream profile information for the 41 surveyed stream reaches has been compared with the catchment area contributing to the streamflow for the reach. The catchment area for each reach was determined using a mechanical planimeter and topographic maps. The results of the assessment are shown in figure 2. Using a regression analysis the following relationship for the data set was identified.

$$S=0.029A^{0.51} \quad ①$$

where S= Streambed longitudinal gradient
A= catchment area (km^2)

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

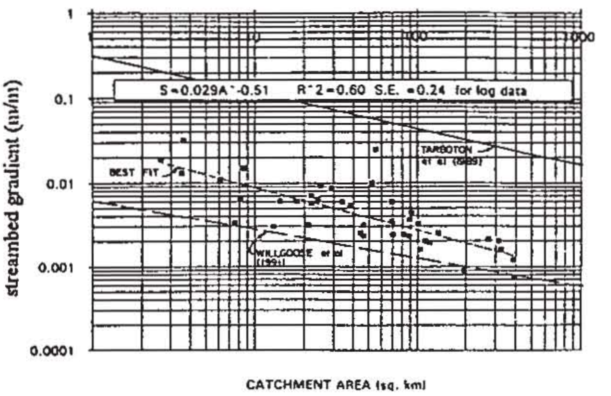

Figure 2 Catchment area versus Streambed longitudinal gradient

The data shows wide variability. For any catchment area the streambed longitudinal gradient was found to vary through a range nearing an order of magnitude. This variability is illustrated in the low coefficient of correlation ($R^2 = 0.60$) obtained for the regression analysis on the log data. However the data plotted between the theoretical results of Willgoose et al (1991) and the field results of Tarbotton et al (1989) for Big Creek Idaho (refer figure 2). The wide variability in the results is likely to be associated with factors such as catchment hydrology, sediment size distribution, cohesion of sediments channel geometry (width, depth) vegetation density and sediment supply to the reach.

4.2 Streamflow analysis

Empirical relationships that relate channel geometry and longitudinal gradients to streamflow are referred to as regime equations and according to Hinwood (1990) were first developed by British engineers working on irrigation systems through India at the turn of the century. Channels that operated without noticeable signs of aggradation or degradation were described as being in regime. Wolman (1955) proposed the following relationship for streambed gradient

$S=aQ^b$ ②

where S= Streambed gradient
Q= representative flow

Regime equations are readily applied to irrigation channels with relatively constant flows. However the variability of streamflow requires the identification or selection of a flow to represent the range of flow encountered within the stream reach. Bray (1982) describes the selection criteria for the evaluation of the characteristic discharge for a river reach as being controversial. According to Bray some researchers have used hydrological criteria such as mean annual flow or the 1.5 year flood flow. Bray cites other cases where the characteristic discharge has been defined in terms of bed load transport through a river reach. Bray (1982) concluded that the 2 year flood flow, (Q_2) based on a log normal distribution satisfied criteria for a data set under consideration.

The two year average recurrence interval (ARI) flood event (Q_2) was selected as a representative flow for this analysis to explore relationships in the streambed gradient data. Flow gauging information for the majority of streams within the data set was not available necessitating an alternate method of streamflow estimation. The rational method of streamflow estimation as outlined by Pilgrim (1987) was used for the estimation of Q_2.

The streambed longitudinal gradient for the 41 stream reaches has been compared with the estimate of 2 year ARI flood event. A plot of the results is shown in figure 3. Using a regression analysis the following relationship was identified

$S=0.018Q_2^{-0.60}$ ③
$R^2=0.60$
$S.E.=0.24$

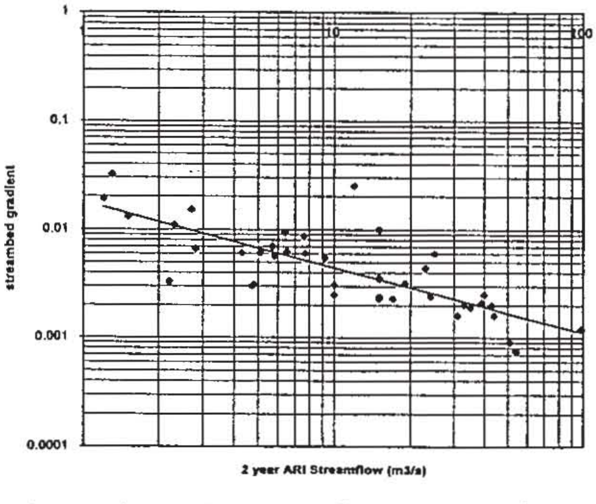

Figure 3 Streamflow versus Streambed gradient

No significant improvement in the quality of the relationship was achieved through the substitution of catchment area with an estimate of streamflow. However the use of the representative flow (Q_2) may make the results more applicable for comparison with waterways in regions other than north east Victoria.

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

4.3 Adjustment for Bankfull Capacity

Twenty four of the surveyed stream reaches had cross section information suitable for an analysis of cross section shape. The depth of flow associated with the estimated Q_2 streamflow for each of the 24 stream reaches was estimated using Manning's equation (refer Chow 1959). Estimates for hydraulic gradient were based on the identified streambed longitudinal gradient between headcuts and nick points and estimates of channel roughness were based on vegetation density. Q_2 flow was estimated to remain within the channel banks for the majority of stream reaches. However for five of the 24 reaches the Q_2 flow was estimated to overtop the channel banks and spread over the adjoining floodplain. For these reaches the lower of the estimated Q_2 and bankfull flow was used for the analysis. A regression analysis was undertaken to develop a relationship between streamflow and the streambed longitudinal gradient. A comparison between the data fit for Q_2 versus streambed gradient and the streamflow adjusted for bankfull flow capacity ($Q_{2/bf}$) versus streambed gradients for the 24 stream reaches with cross section information is provided in table 2. The results indicate a better fit for the Q_2 analysis without adjustment for bankfull flow.

Table 2 Regression analysis results for streamflow analysis with and without adjustment for bankfull flow

representative flow	a	b	R2	coeff
Q_2	0.022	-0.67	0.75	0.18
$Q_{2/bf}$	0.016	-0.58	0.59	0.23

4.4 Sediment size analysis

For each stream reach the A and B axis of the dominant larger sediments comprising the streambed sediments were recorded and the streambed sediments categorised. The limited data set and simple method of sediment size analysis necessitated the grouping of the sediments into the four broad classes outlined in table 3 below.

Table 3 Sediment size categories used for data analysis

Sediment class	Sediment size range
Silts and fine sands	0.02 to 0.2mm
medium to course sand	0.2 to 2mm
fine to medium gravel	2 to 20mm
course gravel to cobbles	20 to 200mm

The streambed longitudinal gradients recorded for each of the sediment size classes in the data set are shown in figure 4

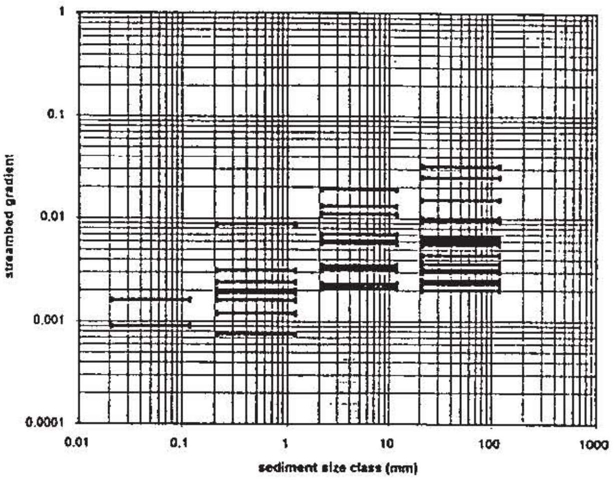

Figure 4. Sediment size analysis

The results indicate a range of streambed longitudinal gradients encountered for each of the streambed sediment categories. The limited accuracy of the analysis and variability in the results suggest further and more detailed analysis of the data set is required in order to make use of the sediment size information.

4.5 Unit Stream Power Analysis

Stream power is a measure of the energy of flowing water. Unit stream power is a measure of the energy per unit width across a stream. Unit stream power analysis enables the incorporation of a number of the variables (including streamflow, channel roughness and channel geometry) impacting on streambed longitudinal gradient to be assessed. Stream power can be written as:

Power, $(\Omega) = \rho g Q s$
where ρ= density of water
g = acceleration due to gravity
Q = flow rate
s = hydraulic gradient

Stream power per unit width of stream (ω) can be written as

$$\text{Unit stream power } (\omega) = \frac{\text{power } (\Omega)}{\text{water surface width}}$$

Stream power assessments have been used by Brookes (1987) and Simons and Richardson (1966) to the explain the bed form and channel shape. Unit stream power assessments provide an opportunity to incorporate sediment size analysis

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

into the assessment of channel geometry and longitudinal gradient. A plot of unit stream power for the incised channel reaches in which Q_2 was estimated to remained within the channel banks is shown in Figure 5.

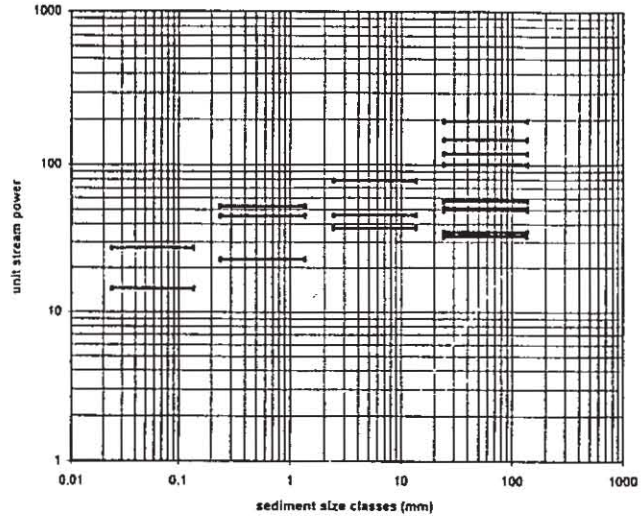

Figure 5 Unit Stream power versus sediment size class

The results of this analysis show an increase in unit stream power with sediment size. The limited accuracy of the sediment size analysis and the variability in the results prevents the development of a relationship. The variability is likely to be associated with factors such as sediment supply and inaccuracies in the estimation of streamflow. None the less the results provide a guide to the unit stream power encountered in the reaches of streams surveyed. Adoption of the lower unit stream powers encountered within each of the four sediment classes may provide a useful tool for the design of stream stabilisation works including channel geometry and streambed longitudinal gradient. The suggested unit stream powers for each sediment size class are shown in table 4.

Table 4 Suggested unit stream power for the design of stream stabilisation works.

Sediment size class	unit stream power
silts and fine sands	15
medium to course sand	25
fine to medium gravel	35
course gravel to cobbles	40

These suggested thresholds for design are in accord with the findings of Brookes (1987). Brookes (1987) found channellised streams undergoing erosive adjustments to have unit stream power in excess of 35w/m^2. Adoption of the criteria outlined in table 4 would most likely result in a conservative design of streambed stabilisation work

5. CONCLUSIONS

Wide variability was found in the streambed gradients identified from the streambed surveys included in this review. The variability in the streambed gradients found is likely to be associated with factors such as sediment size distribution, sediment supply to the reach, soil cohesion, streamflow and vegetation. The variability in the streambed gradients and the range of variables impacting on the stream reaches prevents the use of the results as a deterministic tool. However the results provide a useful indication of the streambed gradients found for a range of streams in north east Victoria. In this respect the results of the review may provide a useful check of streambed gradients identified by alternative means such as streambed surveys unit stream power analysis or shear stress assessments.

Unit stream power analysis provide a means of incorporating a number of the factors impacting on channel geometry into the assessment of streambed gradients. Some variability was found in the unit stream powers estimated for the stream reaches. This variability could be associated with quality of the streamflow estimates and sediment size analysis together with factors such as sediment supply to the reach. None the less the results of the unit stream power assessment may be a useful aid to assist design of streambed stabilisation works.

6. REFERENCES

Anon, 1993. North East Regional Landcare Plan Towards sustainable land use. Department of Conservation and Natural Resources, Victoria.

Bray, D.I., 1982. Regime Equations for Gravel-Bed Rivers in Hey, R.D., Bathurst, J.C., Thorne, C.R., (Eds) 1982. Gravel-Bed Rivers John Wiley and Sons Ltd., Chichester.

Brookes, A., 1987. The Distribution and Management of Channelised Streams in Denmark, Regulated Rivers, Vol. 1, pp. 3-16.

Chow, V.T., 1956. Open-Channel Hydraulics, McGraw-Hill Koakusha, Ltd., Tokyo.

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

Erskine, W.D., Rutherfurd, I.D., Tilleard J.W., 1990. Fluvial Geomorphology of the Tributaries to the Gippsland Lakes. Report to the Department of Conservation and Environment, Victoria. Ian Drummond and Associates Pty. Ltd., Sale, Victoria.

Hack, J.T., 1957. Studies of Longitudinal Stream Profiles in Virginia and Maryland. U.S. Geol. Surv. Prof. Paper, 294B,

Hardie, R, 1993. Review of stream profile information for catchments of North East Victoria. Project report submitted in partial fulfilment of the requirements for the Degree of Master of Natural Resources University of New England Armidale.

Hinwood, J.B., 1990. River Hydraulics. A Three Day Workshop for Professional Staff, Part B. Monash University, Melbourne.

Ian Drummond and Associates Pty. Ltd., 1991. Lower Johnstone Creek Steam Stabilisation Strategy. Shire of Alexandra River Improvement Trust, Alexandra, Victoria.

Ian Drummond and Associates Pty. Ltd., 1989. Brankeet Creek Stream Management Strategy. Ancona Valley Landcare Group. Ancona. Victoria

Ian Drummond and Associates Pty. Ltd., and Michael Read and Associates, 1988. Economic Evaluation of a proposed stream management program in the Ovens River Catchment. Ovens and King Trust.

Ian Drummond and Associates Pty. Ltd. 1988 Shire of Mansfield, Stream Management Strategy. Shire of Mansfield.

I.N. Drummond and Associates Pty. Ltd. 1984a Shire of Alexandra River Improvement Trust Master Plan. Shire of Alexandra.

I.N. Drummond and Associates Pty. Ltd. 1984b Shire of Seymour River Improvement Trust Master Plan. Shire of Seymour.

I.N. Drummond and Associates Pty. Ltd. 1984c. Black Dog Creek Improvement Trust Master Plan. Black Dog Creek Improvement Trust.

I.N. Drummond and Associates Pty. Ltd. 1984d. Kiewa River Improvement Trust Master Plan. Kiewa River Improvement Trust.

Lane, E.W., 1957. A study of the Shape of Channels formed by Natural Streams flowing in Erodible Material, in M.R.D. Sediment Series No.9, U.S. Army Engineer Division, Missouri River, Corps Engineers, Omaha, Nebraska.

Pilgrim, D.H. (Ed) 1987. Australian rainfall and Runoff: A Guide to Flood Estimation. The Institute of Engineers, Australia, ACT.

Rutherfurd, I.D., 1993. Geomorphic Review of the Indigo Creek Stream Stabilisation Strategy. Black Dog Creek Improvement Trust.

Sherrard, J., 1990. Fluvial Geomorphology of Yackandandah Creek - Implications for Stream Management. Report for Kiewa River Improvement Trust, Ian Drummond and Associates Pty. Ltd., Wangaratta, Victoria.

Simons, D.B., Richardson E.V., 1966 Resistance to Flow in Alluvial Channel. Paper 422-J U.S. Geological Survey Professional Paper.

Standing Committee on Rivers and Catchments, Victoria, 1991. Guidelines for Stabilising Waterways. Rural Water Commission of Victoria, Armadale, Victoria.

Tarbotton, D.G., Bras, R.L., Rodriguez-Iturbe, I., 1989. Scaling and Elevation in River Networks, Water Resources Research, Vol. 25, pp 2037-2051.

Tilleard, J.W., 1984. Master Plan - Ovens and King River Trust. Report to Ovens and King River Improvement Trust by Ian Drummond and Associates Pty. Ltd., Wangaratta, Victoria.

US Army Corps of Engineers Water Resources Support Centre 1982. HEC-2 Water Surface Profiles Users Manual Computer Program.

Willgoose, G., Bras, R.L. , and Rodriguez-Iturbe, I., 1991. A physical explanation of an observed link-area slope relationship, Water Resources Research, Vol. 27, No. 7, pp 1697-1702.

Wolman, M.G., 1955. The Natural Channel of Brandywine Creek, Pennsylvania. U.S. Geological Survey, Prof. Paper 271.