Hydraulic - Geomorphic Assessment of the Tumut River

John Paul Bucinskas BE(Civil) MEngSc *

ABSTRACT:

An hydraulic - geomorphic assessment of the Tumut River has been undertaken in order to provide an improved understanding of the processes occurring on the river and to provide a technical framework to base a revised river management strategy. This paper has been prepared to present a summary of the findings of the study and to encourage further use and research of the techniques developed as a method to quantify river behaviour.

The Tumut River has a long history of erosion and channel changes resulting from both natural and human induced changes in the catchment. The inter-catchment diversions of the Snowy Mountains Hydro -Electric Scheme and regulation of flows by Blowering Dam has caused a change in the flow regime.

The assessment technique involved an analysis of the hydraulic - geomorphic slope with consideration to channel stability. A tractive stress duration diagram was also developed in order to quantify the effect of the change in flow regime on the stability of the Tumut River. The concept of tractive stress was also investigated as a tool to assist in the design of river management works.

1. INTRODUCTION

The management of unstable rivers has traditionally been undertaken using structural means with little understanding of the processes causing the instabilities. This study provides an improved understanding of the processes occurring on the Tumut River by analysing the hydraulic and geomorphic properties of the river channel.

The aim of the hydraulic - geomorphic assessment is to quantify the effects of the changed flow regime (the hydrology) with consideration to the hydraulic and geomorphic properties of the river system to ensure that scientific and engineering judgement is integrated into the river management solutions. The hydraulic - geomorphic assessment undertaken can only be considered as a basic assessment as the river parameters used in the analysis are averaged for long river reaches and only one hydraulic and geomorphic equation was used.

The technique adopted in the study is based on the approach used by river engineers in Europe and is to the best of the author's knowledge, the first time such an analysis has been undertaken in Australia.

The main components of the hydraulic - geomorphic assessment undertaken on the Tumut River include:

- An application of the ***hydraulic-geomorphic slope*** concept to analyse the stability of the bed and bank material.
- A ***tractive stress duration analysis*** to quantify the effect of the changed flow regime on channel stability.
- To investigate the concept of ***tractive stress*** as an approach to channel stabilisation work design
- To estimate the stable channel properties of the Tumut River including width and meander geometry

This paper summarises the hydraulic - geomorphic slope and tractive - stress duration analysis components of the more detailed study undertaken by the Department of Land and Water Conservation (1995).

2. DESCRIPTION OF THE TUMUT RIVER

For the purposes of this study, the Tumut River was sub-divided into three reaches. The criteria used for the sub-division was based on changing hydraulic and geomorphic properties of the river, including the hydrology, bed slope, width, sinuosity and the grain size of the bed material. The river may have been further sub-divided to account for the anabranches (avulsions) but limited time and available data made this impractical. Information from topographic maps, gauging stations and river cross-sections were useful to quickly gain an appreciation of the river.

3. HYDRAULIC-GEOMORPHIC SLOPE

3.1 Introduction to the Concept

The hydraulic and geomorphic properties of a river channel can be described by numerical equations. The Manning equation has been used to describe the hydraulic properties of the channel and the Meyer-

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* Department of Land and Water Conservation, New South Wales
P.O. Box 582, COFFS HARBOUR, N.S.W., 2450
Telephone: (066) 52 7644 Fax: (066) 52 3936

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

Peter and Muller (1948) bedload equation is used to describe the geomorphology.

Both the hydraulic and bedload equations can be written as a function of depth versus slope and can therefore be plotted on the same chart. The intersection of the hydraulic and bedload equations reveals the theoretical channel slope and this can be readily compared to the actual water surface or bed slope to determine the stability of the river channel.

3.2 The Hydraulics

The equation used to describe the hydraulics of the river channel is the Manning equation and it is well established to be valid for fully rough uniform flow. The derivation of the Manning equation is presented in Henderson (1966) and is defined as follows:

$$Q = \frac{AR^{2/3}S^{1/2}}{n}$$

where: Q = Discharge (m^3/s),
A = Cross-Sectional Area of flow (m^2)
R = Hydraulic Radius (m)
S = Slope (m/m)
n = Manning's Roughness Coefficient

The roughness coefficient firstly needs to be determined from gaugings of the river, using the actual cross-sections and slopes. This will provide an accurate estimation of n and will prevent having two unknowns in the analysis which follows.

In order to simplify the computations, the cross-section has been assumed to be represented as a wide rectangular section and the hydraulic radius, R, has been assumed to be equal to the depth, D. This assumption is reasonable when the width/depth ratio, $B/D>10$. That is,

$$R = \frac{A}{P} = \frac{BD}{B+2D}$$

and if

$$\frac{B}{D} > 10$$

then

$$R \approx D$$

On the Tumut River the average width B = 40 metres and the average depth D = 3 meters, giving B/D = 13 and therefore it is reasonable to consider the channel to be wide and assume $R=D$.

The Manning equation was then rewritten in terms of depth as a function of slope.

$$D = \frac{Q^2n^2}{(B^2S)^{3/10}}$$

and the specific hydraulic conditions in each reach were then plotted on the depth versus slope curve using the bankfull discharge. The sensitivity of changes in the estimated width, B and Manning's roughness coefficient, n were checked and the best estimate of the hydraulic conditions representing the actual reach was chosen for comparison to the geomorphic conditions.

This was achieved by firstly assuming that the water surface slope is equal to the bed slope in each reach. That is, uniform flow conditions in a prismatic channel where $S_f=S_o$. The average width of the channel was determined from the bankfull width of the channel from the cross section information. The Manning's roughness coefficient, n was then determined as the level and slope of the water surface was known at each of the cross-sections.

3.3 The Geomorphology

It is important to firstly gain an appreciation of the fluvial geomorphic aspects of the Tumut River channel before an attempt is made to quantify them.

3.3.1 The Dominant Discharge

The dominant discharge is the flow which is considered to be the channel forming flow. Although there is no universal method to estimate the dominant discharge, most geomorphologists will agree that it is best estimated as the bankfull flow.

The Tumut River however experiences bankfull flows for approximately 6 to 9 months of the year due to the inter-catchment diversions of the Scheme and regulation by Blowering Dam. It is therefore important that the prolonged duration of the bankfull flows is accounted for in the analysis.

The dominant discharge selected for the Tumut River in this study was the bankfull flow which has been considered to be equivalent to the present operational channel capacity flows which varies from 108 m^3/s upstream of the Goobarragandra River confluence

(Reach 1) to 113 m^3/s downstream of the Goobarragandra River (Reaches 2 and 3).

3.3.2 The Effect of Bedforms

The bedform of the Tumut River, as with any river, varies in both space and time. The grain size in the bed varies between the pools and riffles. The bed of the Tumut River has been observed to have an armoured layer on the riffles. It is suggested that the material in the pools however may become active bedload during bankfull flows.

3.3.3 Choice of Representative Grain Size

The representative grain size is a critical component of the geomorphic assessment in terms of the sensitivity of the bed load equation. In this assessment a single sediment size needs to be chosen to represent the highly variable nature of the reach being modelled.

For the purposes of this assessment, three different sediment sizes were chosen for each reach to represent the material in ***the armoured riffles, the pools*** and at ***the toe of the bank***. The armoured riffle material was sampled using the "grid sample" method. The material in the pools was assumed to be of the same composition as the material beneath the armoured riffles and was taken as the D_{50} of the sampled material which had undergone a standard sieve analysis. The material at the toe of the banks, which is the zone which will predominantly contribute to bank erosion, was also represented. Although the material is cohesive, a non-cohesive equivalent grain size was crudely estimated by using the grain size translation curve prepared by Hjulstrom in 1935, which is based on the threshold velocity of various grain sizes. The work by Hjulstrom is presented and discussed in Graf (1984).

Based on the methodology described above, the following grain sizes were chosen to be representative of the Tumut River reaches for the bed load computations.

	Reach 1	Reach 2	Reach 3
Riffle	55 mm	47 mm	56 mm
Pool	19 mm	23 mm	20 mm
Banks	5 mm	5 mm	5 mm

Table 1 - Selected representative Grain Sizes

3.3.4 The Bedload Equation

The equation used to describe the channel geomorphology in this study is the Meyer-Peter and Muller (1948) bedload equation. The Meyer-Peter and Muller (1948) bedload equation is based on experimental data fitting, is hydraulically backed, and is expressed in terms of shear stress as:

$$\gamma_w \frac{Q_s}{Q}\left(\frac{k_s}{k_r}\right)^{3/2} hS = 0.047\gamma_s'' d_m + 0.25\left(\frac{\gamma_w}{g}\right)^{1/3} g_s''^{2/3}$$

where:

γ_w = the specific gravity of water

Qs/Q = the proportion of the total flow contributing to bedload transport

k_s/k_r= a quantity that relates to the bedform roughness

h = the mean depth

S = the slope of the energy line

γ_s = the specific gravity of the bed material

γ_s'' = the specific gravity of the bedload weighed under water = $\gamma_s - \gamma_w = \gamma_{s'} - 1$

d_m = the "effective diameter" of the bed material

g = acceleration due to gravity

g_s'' = the specific bedload transport weighed under water

This is equivalent to:

Shear Stress $_{(total)}$ = Shear Stress $_{(threshold\ of\ movement)}$ - Shear Stress$_{(remaining\ for\ bed\ load\ transport)}$

Since we are designing a channel for zero bed load transport then the last term of the equation is dropped and the equation becomes:

Shear Stress $_{(total)}$ = Shear Stress $_{(threshold\ of\ movement)}$

or

$$\gamma_w hS = 0.047 \frac{Q}{Q_s}\left(\frac{k_r}{k_s}\right)^{3/2} \gamma_s'' d_m$$

The quantity $(k_r/k_s)^{3/2}$ relates the bed form roughness to the grain size roughness and can conservatively be assumed to be equal to 1. Similarly the quantity Q_s/Q=1 for a wide channel without the influence of the sides of the channel. Under these two assumptions the equation is simplified and can be rewritten with depth as a function of slope as

$$h \cong 0.047\gamma_s'' d_m / \gamma_w S$$

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The value of 0.047 is the calibration factor (representing the Froude Number of the sediment) and defines the beginning of bedload transport. For absolute rest it is necessary to calculate with a calibration factor of 0.030.

3.3.5 Theoretical Hydraulic - Geomorphic Slope

The theoretical hydraulic - geomorphic slope was estimated by plotting the hydraulic conditions as defined by the Manning equation against the geomorphic conditions as defined by the Meyer-Peter / Muller (1948) equation. The equations are plotted with depth and slope as the axes. The curves intersect at a point which defines the theoretically stable condition. This can be compared to the actual water surface slope to determine whether or not the river is in hydraulic - geomorphic equilibrium.

The curves were plotted for all three river reaches using calibration factors of both 0.030 and 0.047. The plot using a calibration factor of 0.030 for Reach 1 is shown in Figure 1 and shows that the riffle material is on the stable side for equilibrium conditions (ie. to the left of the present water surface slope). The plot using a calibration factor of 0.047 shows that the pool material is on the unstable side and this supports the theory and observations that the pool material is active bedload during bankfull flows. The bare bank material is highly unstable as expected.

The hydraulic - geomorphic slope concept could be further used to analyse various river rehabilitation options such as channel widening.

4. TRACTIVE STRESS DURATION ANALYSIS

4.1 Methodology

The average tractive stress duration diagram is developed from flow duration and rating information which represent the average conditions on the river. The methodology involves the selection of flow duration curves which represent the average river conditions. It is then necessary to develop a rating to convert the flows into depths. The depths can then be used to estimate the tractive stress, assuming that the channel is hydraulically wide and the depth is approximated as the hydraulic radius.

The methodology is summarised as follows:

$$Flow \xrightarrow{Rating} Depth \xrightarrow{\gamma DS} TractiveStress$$

This procedure is used to convert the flows in each probability interval on the flow duration curve to form the tractive stress duration curve.

The average tractive stress is defined by the equation:

$$\tau = \gamma D S_0$$

where τ is the average tractive stress, γ is the specific weight of water, D is the depth of flow and S_o is the bed slope (which equals the energy or friction slope for uniform flow). It should be noted that the bedform and channel form roughness are assumed to be equal to 1 in this form of the equation.

The tractive stress duration curve can then be derived from the flow duration curves for the various flow duration scenarios which were taken as pre-Snowy Mountain Scheme (pre 1959), pre Blowering Dam (1959-1968) and post Blowering Dam (1968 to present).

The critical tractive stresses, defined as the tractive stress at the threshold of movement, can then be superimposed on the tractive stress duration curves to estimate the frequency that the thresholds are exceeded under the various flow duration scenarios. At this point, the factor that the banks have no recovery period due to the prolonged high flows, can be accounted for by having a lower tractive stress rating for the bare banks as compared to the vegetated banks.

4.2 Results

Figure 2 shows the results of the tractive stress duration analysis undertaken on the Tumut River.

The curves were also used to estimate the erosion potential of the Tumut River caused by the change in flow regime. The erosion potential is estimated as the area under the tractive stress duration curve and above the critical tractive stress of the material being considered. The erosion potential of the bank material was found to be presently 5 times the natural pre-Snowy channel.

5. TRACTIVE STRESS APPROACH TO CHANNEL STABILISATION DESIGN

The tractive stress approach to channel stabilisation design has been extensively used by river engineers in Europe and America and its simplicity makes it a useful tool to design river restoration works.

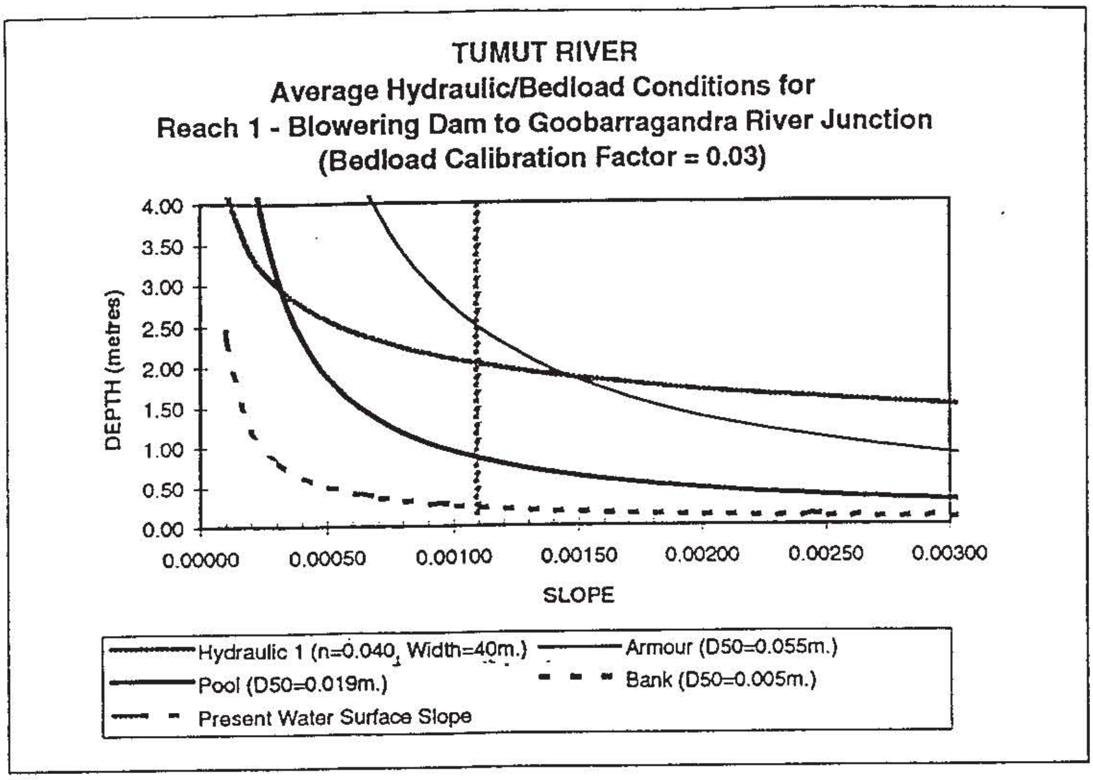

Figure 1 - Average hydraulic - bedload conditions for Reach 1.

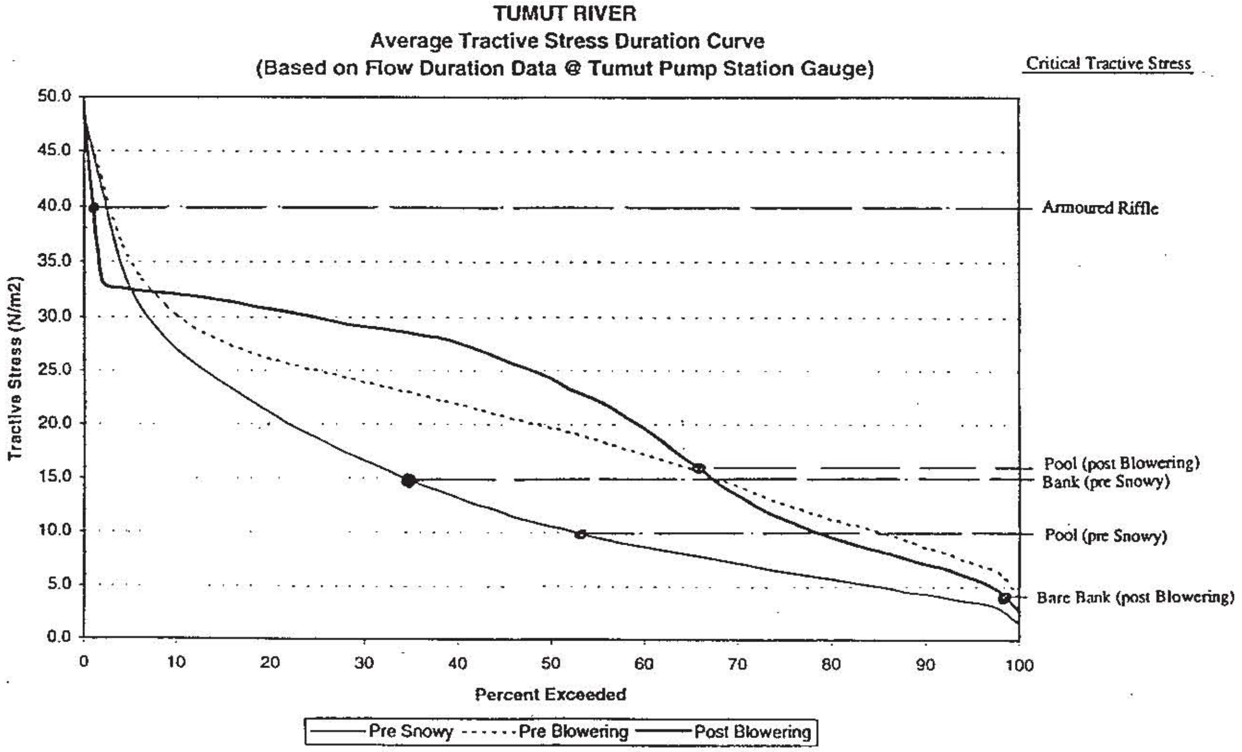

Figure 2 - Tractive Stress Duration Curves

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The approach involves estimating the tractive stress imposed on the banks and comparing this with the tractive stress rating of the bank material. The ***tractive stress rating*** is also referred to as the ***bank competence*** or the ***critical tractive stress*** of the bank material. Table 2 summarises some basic tractive stress ratings used by the Bavarian river engineers.

Bank Material Type	Tractive Stress Rating (N/m^2) - (Csallner, 1984)
Bare Bank (Sand-Gravel)	10 - 15
Willow Revetment	70
Rockwork (dumped rock) with an average diameter of 0.4m. (ie. size currently used on the Tumut River)	150
Rockwork (coarse dumped rock) with an average diameter of 0.8 to 1.0m.	240

Table 2 - Tractive Stress Ratings

The average tractive stress is estimated using the equation (assuming D=R):

$$TS_{av} = \gamma D S$$

The actual tractive stress is then calculated by accounting for adverse conditions at the site by using the appropriate tractive stress multipliers summarised in Table 3.

Adverse Factor	Multiplier of the Average Tractive Stress	
	from German DIN	from Lane (1955)
Acute Angle	*2	* 1.1 to 1.7 depending on the degree of sinuosity
Right Angle	*3	
Prolonged Duration	*2	not presented

Table 3 - Tractive Stress Multipliers

The design tractive stress is then estimated by multiplying the actual tractive stress by a safety factor (1.5) to account for other variables such as unusually high stress during flood events or construction irregularities.

The design tractive stress for the Tumut River was estimated as 180 N/m^2. Bank protection works on the outside of bends will require a tractive stress rating of this magnitude to ensure stability of the works. From this basic assessment it is apparent that only rockfill protection works will stabilise the banks and the rock will require to have a minimum average diameter of 0.5 to 0.6 metres.

6. CONCLUSIONS

The hydraulic - geomorphic assessment technique was found to be a useful way to quantify and analyse the hydraulic - geomorphic processes on the Tumut River.

The analysis of the hydraulic - geomorphic slope quantified the equilibrium conditions for the bed and bank materials. The tractive stress duration analysis allowed the effects of the change in flow regime to be quantified. The tractive stress approach was also used to provide a quick assessment of the most suitable bank protection option.

There is a need to further research the technique as a viable tool for use in river management in Australia. The use of the tractive stress approach also needs to be further researched as river engineers / managers in Europe and America have found the approach useful for assessing river rehabilitation works.

This paper has been prepared to present the findings of the first basic assessment of the Tumut River and to encourage further discussions and research in this area by river managers in Australia.

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