26. HYDRAULIC MODEL CALIBRATION USING A MODERN FLOOD EVENT: THE MAE CHAEM RIVER, THAILAND

R. Kidson[1], *K.S. Richards*[1] *& P.A. Carling*[2]

(1) Department of Geography, University of Cambridge, Downing Place Cambridge CB2 3EN, UK. e-mail: rlk23@cam.ac.uk
(2) Department of Geography, Southampton University, Highfield Southampton, SO17 1BJ, UK.

ABSTRACT

Palaeohydrological studies in the subhumid tropics, particularly South East Asia, are uncommon. This paper presents initial results from the Mae Chaem catchment, Chiang Mai Province, northern Thailand. The lower Mae Chaem River is a steep, bedrock-confined channel, passing through a slot canyon, the Ob Luang Gorge. Despite the subhumid climate, the Mae Chaem has preserved palaeoflood evidence, providing an opportunity for a precedent regional palaeohydrological study. Highly seasonal monsoonal flooding is a defining hydrological feature of modern northern Thailand. In the Mae Chaem catchment, the 2001 flood was the largest in living memory, and left a legacy of abundant flood debris and slackwater deposits along the river margins. Uncertainty associated with palaeohydraulic reconstructions is well recognised, but difficult to quantify, especially for a critical model parameter, the Manning's roughness coefficient 'n'. The detailed 2001 flood evidence presents an opportunity to calibrate Manning's n in a reach-scale hydraulic model. This more realistically constrains this parameter, which is then applied to a palaeoflood in the reach. The analysis demonstrates that where a reach exhibits strong sensitivity to Manning's n, initial constrainment of this parameter is essential, as uncertainty is propagated and amplified in subsequent discharge and return period estimations.

1 INTRODUCTION

The objective of palaeoflood reconstructions is most often to generate a discharge estimate (or retrodiction) for specific palaeofloods for which field evidence of stage (i.e. maximum flood water height) are available. Hydraulic models are used to generate these discharge estimates from stage indicators. As with all models, accuracy and validity of estimates is governed by model calibration quality. In 1-D hydraulic models utilising the Manning formula for uniform flow, calibration of the roughness coefficient, the parameter 'Manning's n' is required for each reach. Whilst direct means of accurately quantifying Manning's n continue to evade fluid dynamicists, the 'visual estimation method' (*Barnes*, 1967) continues to be widely used, in which a reach is compared with photographs of reaches of known Manning's n. For contemporary flow modelling, further Manning's n refinement (using flow data) permits optimal calibration. Manning's n varies with scale (*Yen*, 2002) and with flow stage (*Yen*, 1992) but the usual procedure is reach-scale calibration. This calibration procedure is severely compromised in the palaeoflood case,

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because hydraulic modelling of a palaeoflood typically has only sparse calibration evidence available (sporadic palaeostage indicators (PSIs: *Kochel and Baker*, 1982) distributed along the reach). Hence, Manning's n is usually estimated arbitrarily by the investigator (*Miller and Cluer*, 1998), and accuracy of palaeoflood discharge estimates is often untested. This 'calibration' inaccuracy in palaeoflood discharge estimates is compounded as the 'visual estimation method' was developed for alluvial, lowland reaches. In contrast, palaeoflood studies are ideally conducted in bedrock-confined channels, as the assumption of cross section geometric constancy over time cannot be made with alluvial channels (*Kochel et al.*, 1982). In bedrock-confined channels, application of the 'visual estimation method' continues to produce inaccurate results even for modern flows (*Marcus et al.*, 1992). Lacking in the bedrock channel/palaeoflood literature is a method which (1) quantitatively tests discharge estimate accuracy of current techniques and (2) offers an alternative approach which may overcome these limitations. This paper explores a method to test discharge estimate accuracy produced by a 1-D hydraulic flow model. The approach constructed an accurate reach hydraulic model, calibrated it using a recent flood, and applied it to palaeoflood evidence. The August 2001 flood was the largest in living memory for the lower Mae Chaem River (confirmed via a systematic catchment oral survey). Surveyed stage indicators and gauged flood peak data were used to calibrate Manning's n. Having so constrained Manning's n, the model was applied to estimate discharge and return periods for a palaeoflood in the reach, exploring specifically the issue of uncertainty propagation and amplification in this common palaeoflood study objective.

1.1 Study site

The lower Mae Chaem River (Chiang Mai Province, northern Thailand) is a bedrock-confined channel incised in steep mountainous topography. Climate is strongly monsoonal (mean annual rainfall 970mm; temperature 25.6°C). The study reach was 1.5km in length, with a 48yr instrumented gauging record (1954-2001) and mean annual peak discharge of 420 m^3s^{-1} (see *Website* for photograph). The reach is immediately downstream of a major bedrock gorge, 'Ob Luang', in the vicinity of which are many PSIs from prior floods, and dating of some of these is in progress. PSI types include classic silt and sand slackwater deposits (in main channel terraces or gullies); timber logs lodged in gorge caves of various elevation; and imbricated boulders. Stage indicators from the 2001 flood include silt lines on buildings, vegetation and litter debris ('trashpoints'), tree scars, and slackwater deposits.

1.2 The survey and model

A reach topographic survey was undertaken by total station and differential global positioning system (D-GPS). Fifteen cross sections (100m spacing) plus long profile were surveyed. At each cross section, stage evidence was surveyed of the 2001 flood, and any higher palaeofloods. These data are presented in Figure 1. Average reach slope was 0.0013. The gauging station 'P14' is located on the downstream reach boundary. The 2001 flood of the Mae Chaem River at P14 occurred at 0400 hrs on 13 Aug, with a peak stage of 7.98 m (283.78 msl), and a discharge of 794 m^3s^{-1} (extrapolated from the rating curve - data courtesy of the Thai Royal Irrigation Dept). A 1-D step-backwater hydraulic model was used, as models of greater dimensionality would not be commensurate with the detail of palaeoflood evidence required for model calibration. HEC-RAS v3.0 modelling package was used.

2 METHODS

2.1 Manning's n calibration

Within HEC-RAS, there are 3 main manipulable components (Manning' n, stage and discharge), implying 2 degrees of freedom. If any two components can be defined (based on observed flow data) the third component can be derived. In a palaeoflood reconstruction, stage is usually available (in PSI form), and Manning's n is the additional component which must be specified to generate a discharge retrodiction. Here, the approach utilised the known stage and discharge of the 2001 flood to calibrate Manning's n within the model: this value of Manning's n can then be used to constrain estimates for palaeofloods of greater magnitude.

2.2 Profile criteria

Hydraulic modelling aims to produce a discharge estimate, based on fitting a water surface profile to available stage indicators at multiple cross sections within a reach. Uncertainty in determining actual peak stage from different PSI types (e.g. trashpoints cf. sand terraces) has been highlighted in the literature (*Jarrett and England*, 2002). Even after culling of non-coherent PSIs from the abundant stage evidence of the 2001 flood (Figure 1), it is necessary to define profile criteria. Three criteria were defined for this study: (1) match the profile to the 'highest trashpoint' for the reach; (2) define a 'best fit' profile through all cross section trashpoints (using a least-squares method) and (3) define a 'reach mean' derived from profiles fitted independently through each cross section. Manning's n was calibrated for each profile criterion at the gauged discharge.

2.3 Discharge retrodiction

Discharge retrodiction was performed within HEC-RAS for one palaeoflood ('Palaeoflood 1' in Figure 1). The field evidence for this palaeoflood consisted of a sand terrace PSI, located at two cross sections, at a substantially higher elevation (3.4m and 3.0m respectively) than the 2001 flood. These sand terraces were assumed to derive from the same event. Discharge retrodictions for Palaeoflood 1 were generated for a range of Manning's n values: the 3 derived from the 2001 flood (2.2), and 4 'reference' values: n = 0.03, 0.04, 0.05, 0.06. This encompassed the Manning's n range typically utilised for sensitivity analyses (*Wohl*, 1998), and potential uncertainty of the roughness-stage relationship for this event. The results are presented in Table 1.

2.4 Return period retrodication

Three flood frequency distributions were fitted to the *annual series* (i.e. peak annual discharge data) for the reach gauging station: the Log-Normal, Gumbel EV1 and Log-Pearson Type III. Return periods were calculated based on extrapolation of these distributions from these data to the range of discharge retrodictions produced in 2.3. The results are presented in Figure 2.

3 RESULTS

The Manning's n derived for each profile-fitting criterion were: (1) highest trashpoint: n=0.048; (2) best fit: n=0.0307; (3) reach mean: n=0.0311. Table 1 illustrates the range of discharge estimates (1200 – 2050m^3s^{-1}) for Palaeoflood 1 with different Manning's n, indicating relatively high discharge sensitivity to Manning's n. When the return periods for this range of discharges were calculated (Figure 2), they imply return period estimates with a wide variation over 2 orders of magnitude, even within a single flood frequency distribution. Thus, initial uncertainty in selection of Manning's n propagates and amplifies uncertainty in discharge estimates, and then in flood frequency estimates. This analysis demonstrates the importance of initial constraint of Manning's n, if discharge and return period estimates are to be meaningful.

(1) Manning's n: 2001 Flood	Discharge Retrodiction (m^3s^{-1})	(2) Manning's n: Reference Values	Discharge Retrodiction (m^3s^{-1})
0.0307	1390	0.03	1205
0.0311	1450	0.04	1700
0.048	2010	0.05	2012
		0.06	2050

Table 1. Discharge retrodictions for Palaeoflood 1. Estimates shown are based on (1) three 2001 flood Manning's n values (derived for each profile criterion) and (2) four Manning's n reference values.

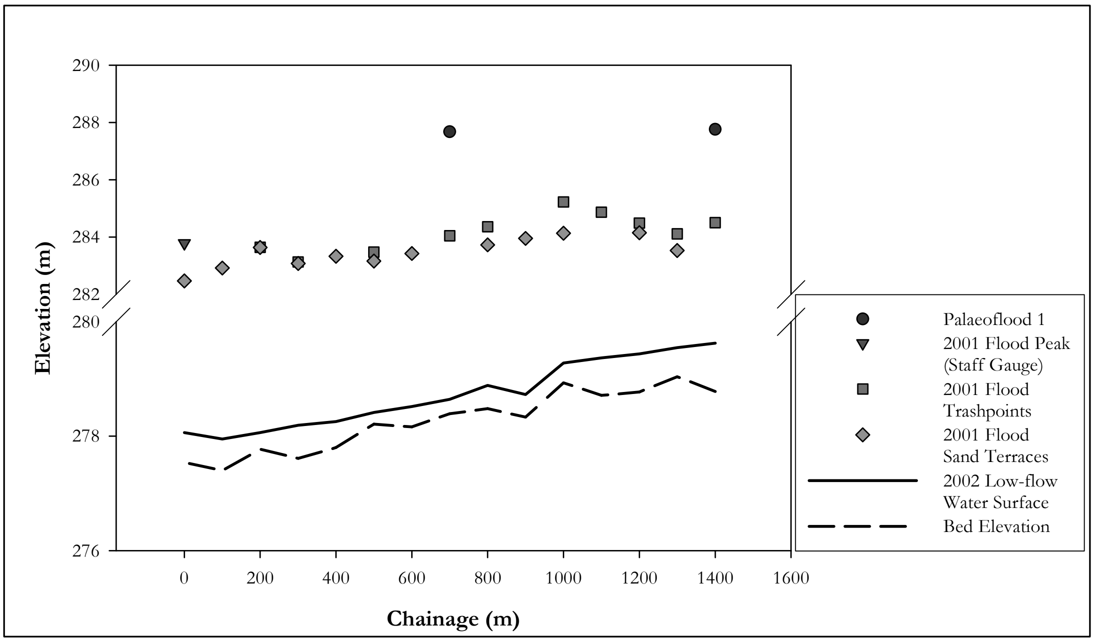

Figure 1. Long profile of the Mae Chaem River study reach, showing the position of several peak stage indicator types.

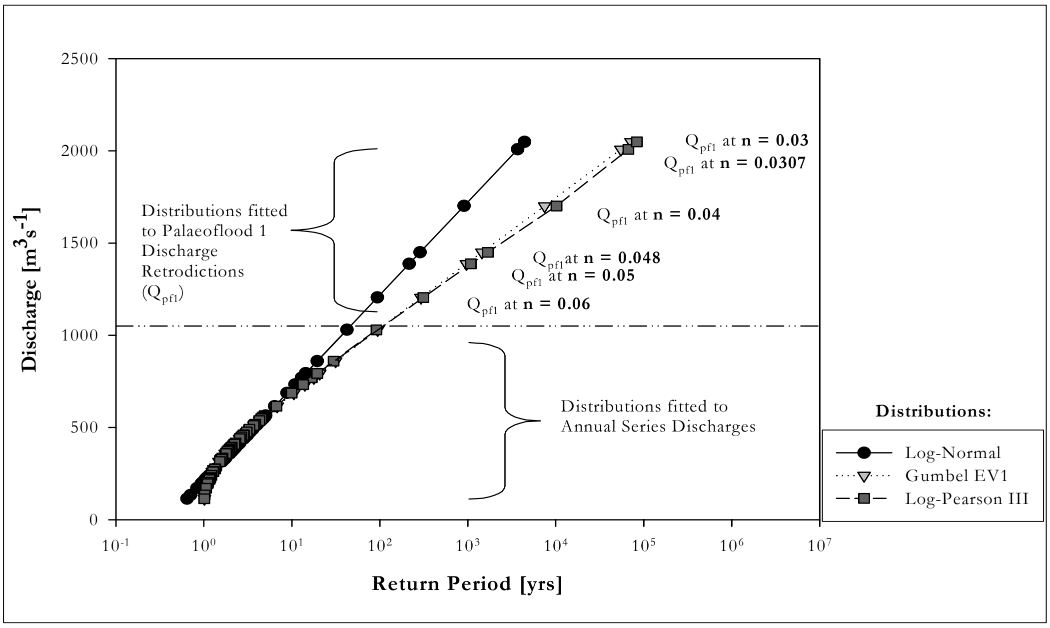

Figure 2. Three commonly-applied flood frequency distributions, fitted to the Mae Chaem discharge data, to estimate return periods: the Log-Normal, Gumbel EV1 and Log-Pearson III distributions. The upper pane illustrates the range of possible discharges for one event, Palaeoflood 1 [Q_{pf1}], according to which value of Manning's n is selected for this event. The corresponding range in potential return period for this single event are shown, as modelled by each distribution.

4 DISCUSSION

In this analysis, a coarse reach scale has been employed, since although higher resolution analysis is possible for the 2001 flood, such resolutions are rarely feasible in the context of an unknown palaeoflood. Similarly, scope for more complex flow modelling (e.g. unsteady flow, 2- and 3-D) has been weighed against the calibration PSI evidence available for palaeofloods. Return period estimates can be constrained with independent dating evidence of PSIs (e.g. *Hirsch and Stedinger*, 1987); however not all PSI evidence is datable. One area for further research is the stage-variability of Manning's n, which tends to decrease with rising stage until bankfull stage, at least for alluvial channels. In bedrock gorges the concept of bankfull flow has limited meaning, but higher floods may encounter different sources of flow resistance (e.g. vegetation), and an outstanding challenge for hydraulic modelling of palaeofloods is therefore to quantify this effect. The 2001 flood, whilst substantial, is still smaller than most PSI palaeoflood evidence in this reach. Hence, Manning's n derived for the 2001 flood should be used merely to constrain estimates for events of greater magnitude. The results reported here clearly have difficult implications for prior and future palaeoflood reconstructions which do not have the advantage of a reach-specific modern extreme event as a basis for Manning's n calibration. However, they strongly suggest the need for more research into methods for estimating this critical parameter for hydraulic models.

5 CONCLUSIONS AND RECOMMENDATIONS

This study illustrates that even for a relatively simple palaeoflood modelling exercise, with Manning's n constrained by abundant modern stage data, the decision making process for hydraulic model calibration still involves a degree of subjectivity. Initial uncertainty in Manning's n estimates propagate and amplify as discharge and frequencies are estimated, because of the non-linearities. This increasing uncertainty is a serious problem for palaeoflood studies which seek to define return periods. For the Mae Chaem reach, the importance of the measures taken to constrain Manning's n estimation has been clearly shown. Generally, therefore, the best means to address uncertainty in palaeoflood hydraulic modelling is to (1) cite results from a range of possible decisions, and (2) select and report decision criteria carefully. This is, in effect, another level of 'sensitivity analysis' within the modelling process, one which is not often employed in the hydraulic modelling literature. This approach is recommended as good modelling practice, and is essential for the generation of credible and accurate palaeoflood discharge and return period retrodictions.

6 WEBSITE

This paper is part of a broader comparative study of Manning's n calibration methods that includes the visual estimation method. We are using an 'Expert Panel' approach to collect a large sample of Manning's n 'visual estimations' for the Mae Chaem study reach. A website showing photographs of the reach has been established to collect these estimates. If you wish to particpate please visit our website: http://www.srcf.ucam.org/~rlk23/Manning

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