Regional hydraulic geometry models for Queensland streams

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Abstract

Many catchment models often fail to fully consider the implications of past, present, or future geometry of the stream system. In many instances, historical data can be used to correlate stream geometry with land use changes and landscape protection efforts. The main objective of this study is to collate available channel geometry data in Queensland catchments and develop models to extrapolate or predict channel geometry in similar stream systems. A determination of hydraulic geometry relationships will facilitate management and restoration of rivers and better parameterise the catchment hydrology models. State of the Rivers database compiled by the Queensland Department of Natural Resources and Water (NRW) contains a comprehensive amount of river geometry data for Queensland. We extracted this information for developing regional geometry curves. A number of empirical equations were developed to estimate hydraulic geometry models throughout river networks. Used channel characteristics include bankfull width, depth, shape, slope and discharge at gauging stations. All models are provided with some indication of their error so users can assess the uncertainty in their model predictions. These regional geometry models will be invaluable tools for river assessment, protection, restoration and general management.

Keywords

Channel geometry, catchment, models, geometry curves

Introduction

Assessment of the impact of catchment management and human interactions on water quantity and quality has drawn attention from a broad section of the community. Stream geometry and morphology affects flood frequencies, sediment and pollutant transportation, aquatic habitats and other ecosystem conditions (Singh and McConkey 1989). Particulars of channel geometry are essential to ascertain the effects of land use and management on erosion and sediment deposition, and the time scales over which they occur. Generally catchment hydrology models are being used to assess the sediment generation and transportation (Hateley *et al.*, 2006) and most of these models require stream geometry information to parameterise the model. It is well know that channel geometry varies significantly spatially and temporally and is often difficult and expensive to measure when information is required. A number of techniques have been developed to estimate channel geometry indirectly, using the catchment characteristics, hydrological information and climatic variables, which are easily measured and commonly available (Stewardson *et al.*, 2005). In these techniques, regression relationships have been developed between channel geometry and catchment characteristics (area, slope, vegetations etc), hydrology information (annual mean flow, two-year recurrence intervals) and climatic variables. These relationships are known as hydrologic geometry models or regional geometry curves (Leopold, 1994).

A determination of hydraulic geometry relationships for Queensland catchments is important to quantify the role of vegetation in restricting sediment delivery and to better parameterise the SedNet (Wilkinson *et al.*, 2004) model for local catchment. In addition to the need to know about gross-channel size for sediment generation studies, we also need to know channel geometry to undertake hydraulic habitat assessments as part of environmental flow studies. A wealth of information on river geometry, habitat conditions, riparian vegetation and catchment details are available at the State of the Rivers (SOR) database managed by the Queensland Department of Natural Resources and Water (NRW). Further river flow data recorded at gauging stations across the State are also available in HYDSRTA database at NRW. Using the data extracted from the SOR and HYDSTRA databases channel geometry relations were developed for Queensland Rivers. These relationships are based on average measures of channel top width, mean and maximums depth for various locations across the State. Standard power function was used for fitting regression relationships between dependent and independent variables and separate geometry models for 6 regions and 12 basins were developed. The channel geometry relations were found to vary in relation to catchment area, that is, they are to some degree scale dependent. Therefore different models were developed for catchment areas below and above 8000 km^2. Among the investigated variables, discharge measures provided a better estimator for both channel width and depth at various spatial scales.

This project was conducted under the National Action Plan for water quality and the University of Melbourne conducted the data analysis.

Methods

Channel geometry models for Queensland catchments were developed using the methodology adapted by a Victorian study (Stewardson *et al.*, 2005). Required data for this study were extracted from the State of Rivers (SOR) and HYDSTRA databases managed by Queensland Department of Natural Resources and Water. SOR database contains approximately 7000 surveyed cross-sections throughout most regions in Queensland. These were surveyed by line and inclinometer to bank-full, primarily for assessment of river condition. Extracted data were closely examined for quality and data from selected sites were used in the analysis. Details of catchment area, land use, major soil types and elevation were extracted from GIS and DEM data files provided by Queensland NRW. Further, historical continuous river discharge measures were required to develop the predictive models channel width and depth. Generally this information is only available at river gauging stations and extracted from HYDSTRA database. Data from the surveyed sites close (within 3 km) to gauging stations, were extracted using ARC shapefile coverage of both the survey and gauging station locations. This resulted in a final dataset of 434 gauging stations that had between 1 and 13 State of Rivers surveys within suitable proximity of each station. At each station we determined the catchment area, mean annual flow, and the 2, 5, and 10-year recurrence interval discharges. Channel geometry relations were determined by standard linear-least squares regression on natural log (Ln) transformed variables.

Analysis of covariance (ANCOVA) was used to determine whether statistically significant differences in geometry relations existed between 6 regions and for individual basins. The State of Rivers surveys that also contained information on riparian condition and the effect of riparian vegetation on channel width or depth were also examined using step-wise regression analysis. However, neither percentage of tree cover, bare ground, grass cover nor riparian width were found to explain variation in channel geometry and these were not considered further.

Results and discussion

Width to depth ratio
Variation in the channel width to depth (W/D) in relation to catchment area is shown in Figure 1. The W/D ratio was calculated using average channel depth. The mean W/D for all sites was 19 ± 1.6 and 80 % of sites were between 6 and 38. The ratio of average depth to maximum depth for all surveys averages 0.62. The regression model in relation to catchment area is given below and the coefficient and exponent of the model are comparable with results from Victorian Rivers (Stewardson *et al.*, 2005).

$$\frac{W}{D} = 8.07 \times A^{0.086}$$

A - Catchment area

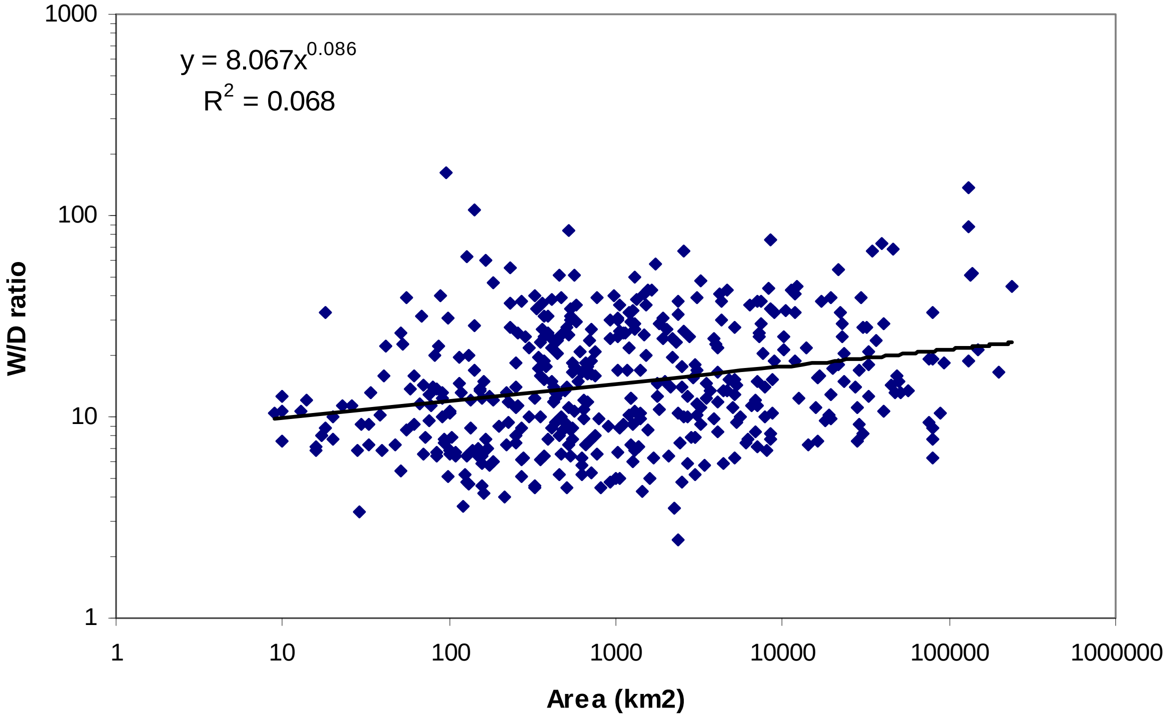

Figure 1. Variation in W/D ratio with increasing catchment area for surveys in the State of Rivers database.

Channel top width

Channel top width varies from 6 to 600 m for the surveyed cross-sections. In general, there is an increasing trend in channel width with increased catchment area and discharge. However, both mean annual flow (MAF) and the 2 year recurrence interval flows (Q_2) provide better statewide predictive models for channel width, with higher correlation coefficients and lower standard errors compared with relations for catchment area. It was observed that channel width does not increase at the same rate in relation to catchment area for major rivers with areas above about 8000 km^2. The result indicates that there is some scale dependency in the channel geometry relations. The regression models were therefore developed for surveys above and below 8000 km^2 (Table 1). Similar models for each regions and basins were also developed.

Table 1. Regression models ($y = a.X^b$) of channel top width in relation to catchment area, mean annual flow (MAF) and 2 year recurrence interval flows (Q_2). n - number of samples analysed. Ln (SE) is the natural log of the standard error of estimated width.

		n	*a*	*b*	SE of *b*	R^2	Ln(SE)
Area (km^2)	**All**	**435**	**9.4**	**0.21**	**0.02**	**0.27**	**0.75**
	<8000km^2	354	6.8	0.27	0.03	0.25	0.73
	>8000km^2	81	12.4	0.17	0.11	0.02	0.83
MAF ($m^3 s^{-1}$)	**All**	**403**	**30.1**	**0.31**	**0.02**	**0.37**	**0.69**
	<8000km^2	331	30.4	0.34	0.03	0.35	0.68
	>8000km^2	72	24.9	0.32	0.07	0.22	0.71
Q_2 ($m^3 s^{-1}$)	**All**	**365**	**5.0**	**0.38**	**0.03**	**0.35**	**0.71**
	<8000km^2	301	4.7	0.39	0.03	0.32	0.70
	>8000km^2	64	8.9	0.31	0.07	0.22	0.72

Mean channel depth

Mean channel depth varies from 0.5 to 18 m for the surveyed cross-sections. Similar to channel width, there is an increasing trend in depth with increased catchment area and discharge. Discharge measures provided better statewide predictive models of channel depth. As with channel width, mean depth does not increase at the same rate in relation to catchment area or all discharge variables for catchment areas above about 8000 km^2. The regression models were therefore recalculated for surveys above and below 8000 km^2 (Table 2).

Table 2: Regression models ($y = c.X^f$) of channel mean depth in relation to catchment area, mean annual flow (MAF) and 2 year flow recurrence intervals (Q_2). n - number of samples analysed. Ln (SE) is the natural log of the standard error of estimated depth.

		n	*c*	*f*	SE of *f*	R^2	Ln(SE)
Area (km^2)	**All**	**435**	**1.17**	**0.13**	**0.01**	**0.16**	**0.62**
	<8000km^2	354	0.78	0.20	0.02	0.20	0.62
	>8000km^2	81	1.31	0.10	0.07	0.01	0.58
MAF ($m^3 s^{-1}$)	**All**	**403**	**2.32**	**0.20**	**0.02**	**0.26**	**0.58**
	<8000km^2	331	2.34	0.26	0.02	0.31	0.57
	>8000km^2	72	2.30	0.14	0.06	0.07	0.58
Q_2 ($m^3 s^{-1}$)	**All**	**365**	**0.83**	**0.23**	**0.02**	**0.20**	**0.61**
	<8000km^2	301	0.68	0.27	0.03	0.22	0.61
	>8000km^2	64	1.36	0.14	0.06	0.08	0.57

Similar channel geometry relations for mean channel depth, for the 6 regions and different basins, were also developed and significant variation between regions was observed. Models for maximum channel depth relations were developed and are essentially the same as those for mean channel depth, except that the value of the coefficient "*c*" in regression models is greater.

The analysis showed that the channel geometry relations for Queensland Rivers are broadly similar to those for Victorian Rivers (Stewardson *et al.*, 2005). In particular there is very little difference in the hydraulic geometry relationship between width and the 2-year recurrence interval flow. We observed the same average trend between width and discharge applies at very large spatial scales. In contrast, the exponents in power functions are smaller and average depths are less for the same discharge in Queensland Rivers. This is probably a consequence of the type of survey used rather than any real difference in channel geometry. In particular, it appears that the channel bank tops have not been consistently identified for both right and left banks and this has led to systematic underestimation of the actual bank height in this analysis.

In general, channel width and depth show better correlation with catchment area and discharge for the 6 regional areas and most basins investigated. There are statistically significant differences in channel geometry relations between some basins and between basin variability accounts for additional variance in width and depth. Basins with the stronger correlations in regression models give more reliable estimates for the exponents in power functions. These suggest that the value of width exponent (*b*) is most likely in the range 0.30 – 0.37, 0.32 – 0.46 and 0.37 – 0.51 for area, MAF and Q_2 based relationships, respectively. Similarly the value of the depth exponent (*f*) is most likely in the range 0.23 – 0.37, 0.29 – 0.50 and 0.33 – 0.59 for area, MAF and Q_2 based relationships, respectively. For basins where there is poor correlation between width or depth and independent variables, it is recommended that the value of exponents be treated as a constant value within the ranges specified above.

Conclusion

Among the independent variables; catchment area, mean annual flow and two year recurrence interval flow examined, mean annual flow (MAF) consistently provided the best predictor of channel width and depth at both basin, regional and statewide scales. Although catchment area does not perform as well at statewide scales, at the smaller scale of individual basins, it is as good a predictor of channel width as MAF. The advantage of employing channel geometry relations based on MAF is that the same relationship can be used in most basins with only minor modification to account for local variability: relations based on catchment area vary to a greater degree between basins. The advantage of employing relations based on catchment area, however, is that area can be predicted with a higher degree of accuracy in GIS spatial modeling frameworks and this might ultimately yield more accurate predictions of channel width and depth at the basin scale.

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References

Hateley, L., Armour, J., Pitt, G., Sherman, B., Read, A., Chen, Y., Brodie, J., & Cogle, A.L. (2006). Sediment and nutrient modeling in the Far North Queensland NRM region. Volume 1. In: *The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting* (Ed) A.L. Cogle, C. Carroll and B.S. Sherman. Department of Natural Resource and Water. QNRM06138.

Leopold, L.B. (1994). *A view of the River*. Harvard University Press, Cambridge, Massachusetts.

Singh, K.P., & McConkey, S. (1989). Hydraulic geometry of streams and stream habitat assessment. *Journal of Water Resources Planning and Management* 115: 583-597.

Stewardson, M., DeRose, R., & Harman., C. (2005). *Regional models of stream channel metrics*, Technical report. Cooperative Research Centre for Catchment Hydrology, Melbourne University, Australia.

Wilkinson, S., Henderson, A., & Chen, Y. (2004). *SedNet User Guide*, A CSIRO land and Water client report for the Cooperative Research Centre for Catchment Hydrology, Australia.