



Department of EARTH SCIENCE

Introduction

Stream discharge through narrow, deep slot canyons can be a major source of groundwater recharge in the arid Southwest. However, these canyons are normally dry except during flash floods, making stream velocity nearly impossible to measure. Various state and federal agencies, including the Utah Department of Natural Resources (UDNR) use the empirical Manning Equation to predict the discharge through artificial slots created for diversion of rivers around coal mines. The Manning Equation estimates average stream velocity, v, as

$$v = \frac{1.49R^{2/3}S^{1/2}}{n}$$

where R is hydraulic radius (cross-sectional area divided by wetted perimeter), S is the slope of the stream bed, and *n* is the Manning roughness coefficient. Stream dishcarge, *Q*, is calculated from the equation

$$Q = AV$$

where A is the cross-sectional area, and V is the velocity as estimated by the Manning Equation. However, it is not obvious that the Manning Equation could be applied to slot canyons or artificial slots as the data base used for development of the Manning Equation did not include either natural streams or artificial structures for which most of the friction occurs along the sides of the channel.

Objective

Our aim is to develop an empirical formula for estimating the Manning roughness coefficient for flow through narrow, deep slots. It is hoped that the new formula will lead to a more realistic design for artificial slot diversions.

Methods

canyons.

To more accurately estimate the roughness coefficient, stream velocity in slot canyons is measured and the roughness coefficient is calculated using the Manning Equation. The measured roughness coefficient, n_M, is then compared with the roughness coefficient as estimated by Jarret (1984) for high-gradient streams. Jarret's equation estimates the roughness coefficient, n₁, as

$$n_I = 0.39 S^{0.38} R^{-0.16}$$

where S is the slope of the stream bed and R is the hydraulic radius.



Use of the Manning Equation to Estimate Stream Discharge through Natural Slot Canyons and Artificial Slots

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Map of Utah showing major rivers and streams. Locations where stream data have been collected are shown.



Locations of slot canyons in and around Southern Utah. Slot canyons are indicated by small dots. Image obtained from http://www.americansouthwest.net/slot_canyons/map.html

Results

Based on analysis of stream measurement data, we have developed an equation for calculating the roughness coefficient. The equation states that the measured roughness coefficient, n_M , is estimated as

 $n_M = 0.873 n_I e^{5.108(\frac{A}{W^2})}$

where n_j is the roughness coefficient calculated by Jarret's equation, A is the cross-sectional area, and W is the width of the stream. This new formula estimates stream discharge with a mean accuracy of 44%.

Site	Aspect ratio (A/W ²)	Measured n	Jarrett's n	
Weeping Rock 1	0.622	0.504	0.164	Outlier removed due to stream segment being too short.
Weeping Rock 2	0.113	0.524	0.174	
Narrows	0.218	0.193	0.071	
Red Cliffs	0.615	4.374	0.110	
Water Canyon 1	0.702	5.307	0.167	
Water Canyon 2	0.703	3.760	0.196	
Deer Creek	0.164	0.101	0.115	
Calf Creek	0.084	0.218	0.104	
Cedar Canyon	0.118	0.278	0.142	
Willis Creek 1	0.105	0.150	0.179	
Willis Creek 2	0.120	0.257	0.178	

Aspect ratio, measured coefficient of friction, and Jarret's coefficient of friction for 11 sites on 8 streams.



Graph of data from 10 sites showing roughness coefficient with respect to aspect ratio.

Conclusion

To ensure better accuracy the new formula will be refined by measurements on additional natural slot canyons in southern Utah and northern Arizona, on a laboratory hydraulics bench and on artificial slot diversions created by UDNR for Lower Robinson Creek and Kanab Creek near Alton, Utah, and for Crandall Canyon Mine in Bear Canyon, Utah. It is hoped that the new formula will lead to a more realistic design for artificial slot diversions.

