Water Science and Technology Library

Ramakar Jha · Vijay P. Singh ·
Vivekanand Singh · L. B. Roy ·
Roshni Thendiyath *Editors*

River and Coastal Engineering

Hydraulics, Water Resources and Coastal Engineering

Springer

Water Science and Technology Library

Volume 117

The aim of the *Water Science and Technology Library* is to provide a forum for dissemination of the state-of-the-art of topics of current interest in the area of water science and technology. This is accomplished through publication of reference books and monographs, authored or edited. Occasionally also proceedings volumes are accepted for publication in the series. *Water Science and Technology Library* encompasses a wide range of topics dealing with science as well as socio-economic aspects of water, environment, and ecology. Both the water quantity and quality issues are relevant and are embraced by *Water Science and Technology Library*. The emphasis may be on either the scientific content, or techniques of solution, or both. There is increasing emphasis these days on processes and *Water Science and Technology Library* is committed to promoting this emphasis by publishing books emphasizing scientific discussions of physical, chemical, and/or biological aspects of water resources. Likewise, current or emerging solution techniques receive high priority. Interdisciplinary coverage is encouraged. Case studies contributing to our knowledge of water science and technology are also embraced by the series. Innovative ideas and novel techniques are of particular interest.

Comments or suggestions for future volumes are welcomed.

Vijay P. Singh, Department of Biological and Agricultural Engineering & Zachry Department of Civil and Environment Engineering, Texas A&M University, USA Email: vsingh@tamu.edu

All contributions to an edited volume should undergo standard peer review to ensure high scientific quality, while monographs should also be reviewed by at least two experts in the field.

Manuscripts that have undergone successful review should then be prepared according to the Publisher's guidelines manuscripts: https://www.springer.com/gp/authors-editors/book-authors-editors/book-manuscript-guidelines

Ramakar Jha · Vijay P. Singh · Vivekanand Singh ·
L. B. Roy · Roshni Thendiyath
Editors

River and Coastal Engineering

Hydraulics, Water Resources and Coastal Engineering

Springer

Editors
Ramakar Jha
Department of Civil Engineering
National Institute of Technology Patna
Patna, India

Vivekanand Singh
Department of Civil Engineering
National Institute of Technology Patna
Patna, Bihar, India

Roshni Thendiyath
Department of Civil Engineering
National Institute of Technology Patna
Patna, India

Vijay P. Singh
Department of Biological and Agricultural Engineering
Zachry Department of Civil and Environmental Engineering
Texas A&M University
College Station, TX, USA

L. B. Roy
Department of Civil Engineering
National Institute of Technology Patna
Patna, India

ISSN 0921-092X ISSN 1872-4663 (electronic)
Water Science and Technology Library
ISBN 978-3-031-05056-5 ISBN 978-3-031-05057-2 (eBook)
https://doi.org/10.1007/978-3-031-05057-2

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2022
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The book is unique in nature by covering the coastal engineering and river engineering aspects related to the engineering solutions with case studies. The Shoreline oscillations are the response of natural endeavors such as wind, wave and storm which are termed as short term or temporary modification. Shore line changes are the phenomenon of permanent modification to a coast induced by natural calamities such as Tsunami, sea level rise and by human intervention such as the improper implication of structures like the groin, detached breakwaters, seawalls and coastal related activities such as dredging and beach nourishment. A suite of meso-scale and submeso-scale processes effect the ocean shoreline properties, such as the mixed layer depth, *sea surface temperature* (SST) and *sea surface salinity* (SSS), which shape the weather and climate conditions by balancing the exchange of mass, momentum, energy and heat between the atmosphere and the ocean. Carrying out conventional bathymetry survey for inter-tidal zones is a tedious and time-consuming process. This demands to use of the remote sensing for such regions. However, remote sensing of intertidal zones has the issues of water clarity and turbidity, which contributes error in mapping the bottom topography.

In the book, the depth values of the inter-tidal zones have been extracted using two methods such as band ratio and tide co-ordinated shoreline method. Moreover, cases studies are done for the assessment of shoreline position, rate of sediment movement, short-term shoreline oscillation and volumetric changes using a most reliable and accepted system of data acquisition and manipulation.

Fisheries sector is another powerful income and employment generator as it stimulates growth of a number of subsidiary industries and is a source of cheap and nutritious food and foreign exchange earner as well. The mathematical models has been used to simulate wave conditions in Mangrol harbours and ports. Moreover, in the Sagarmala project, it is envisaged to develop small tourist cum fishing harbours along the coast. In view of this, a feasibility to develop a small harbour in the open sea near Korlai is studied using mathematical modelling.

Coastal erosion is one of the significant issues throughout the globe. Coastal areas are more prone and vulnerable against the natural and anthropogenic changes that take place along the coast. A lot of developmental activities along the coast are being ubiquitous nowadays, which has a direct or indirect impact on the coastal areas. In the book, the effect of developmental activities on the coast has been studied, and proper measures were made to reduce the impact. Coastal stretches from Ennore creek to Pulicat of Tiruvallur district were considered using DSAS to identify the causes and hotspots of erosion.

In India, 45% of its 7500 km coastline is disintegrated. Infrastructural development like harbour, hinders the ideal sand sediment stream, additionally embankments and groins deter the long shore drift. Such constructions, which are beneficial for infrastructural growth, create problems to nature and part of society lying within those regions. Construction of a seawall seems a beneficial option for addressing the excessive unwanted erosion. For the design and construction of a seawall with increased sustainability, preliminary investigation on structures response to the attacked wave is essential. Such studies have been conducted experimentally, analytically and using numerical tools using commercial packages for wave-structure interaction (WSI) studies are compared. Solvers based on Navier–Stokes equation, volume of fluid (VOF), nonlinear shallow water equations and finite element method (FEM) are compared using literature.

As the ocean covers 70% of earth surface, it has a very significant role in providing the clean energy in the form of tidal energy, tidal currents, wave energy, temperature gradient and salinity gradient which are sufficient enough to meet the global energy demand. The book presents an overview in respect of current state of research and development in the field of tidal energy as this form of renewable energy is considered as most advanced one.

River engineering is another important area of research, which is being extensively used for water resource projects affected by the amount and concentration of sediment transported, heavy precipitation and human interventions including hydropower projects. In this regard, studies related to various aspects have been discussed in the book with some cases studies of Ganga, Mahanada, Tapi and other Himalayan rivers. For the analysis, different numerical and analytical models in support with remote sensing and GIS have been used. Some of the models are generalized reduced gradient technique, magnitude frequency analysis (MFA), computational fluid dynamic (CFD) program-based Flow3D, Mann–Kendall trend test, river hydraulic model and MATLAB/SIMULINK.

Patna, India Ramakar Jha
College Station, TX, USA Vijay P. Singh

Acknowledgements

The editors are grateful to Prof. P. K. Jain, Director, NIT Patna, for his constructive support and encouragement for completing the book. They also thank reviewers for reviewing the papers included in the book.

This book would not have been possible without the support of Indian Society for Hydraulics, CWPRS Pune, and sponsors who supported the annual conference. This book constitutes a portion of the proceedings of conference.

The editors thank all the experts who delivered Keynote address, all the participants, faculties, staff and the students who contributed to the completion of the book. Some of the students are Kamakshi Singh, Saba Khurshid and Ratnesh Kumar.

Finally, the editors acknowledge all those who helped with bringing the book to fruition, especially the authors of all the papers.

Contents

About the Editors

Ramakar Jha is a chair professor at the Department of Civil Engineering and has 30 years of experience in the field of hydrology and water resources engineering. Dr. Jha is presently working as Chair Professor in the Department of Civil Engineering, National Institute of Technology (NIT) Patna-India, which is a Premier Institute in India under the Ministry of Human Resource Development, Government of India. Dr. Jha has served at various levels from Scientist-B to Scientist-E1 at National Institute of Hydrology (NIH), Roorkee, India, and as Professor in the Department of Civil Engineering, NIT Rourkela. He has worked and working as Country Coordinator of UNESCO-GWADI and Principal Investigator for many International (EU-FP7, DAAD, ADB, AUS-Aid) and National research and consultancy projects (ISRO, DST, MoWR, MHRD). Moreover, he served as Chair for many administrative positions and received a couple of international and national awards for research papers. Presently, he is working as Dr. Rajendra Prasad Chair for Water resources under the Ministry of Water Resources, Government of India, in the Department of Civil Engineering, NIT Patna, Bihar.

Vijay P. Singh is University Distinguished Professor, Regents Professor, and Caroline and William N. Lehrer Distinguished Chair in Water Engineering at Texas A&M University. He received his B.S., M.S., Ph.D. and D.Sc. degrees in engineering. He is a registered professional engineer, a registered professional hydrologist and an honorary diplomate of ASCE-AAWRE. He is a distinguished member of ASCE, a distinguished fellow of AGGS, and an honorary member of AWRA, and a fellow of EWRI-ASCE, IAH, ISAE, IWRS and IASWC. He has published extensively in the areas of hydrology, irrigation engineering, hydraulics, groundwater, water quality and water resources (more than 1320 journal articles; 31 textbooks; 75 edited reference books; 110 book chapters; and 315 conference papers). He has received more than 95 national and international awards, including three honorary doctorates. He is a member of 11 international science/engineering academies. He has served as President of the American Institute of Hydrology (AIH), Chair of Watershed Council of American Society of Civil Engineers, and is currently President of American Academy of Water Resources Engineers. He has served/serves as editor-in-chief of three journals and two book series and serves on editorial boards of more than 25 journals and three book series. His Google Scholar citations include: 65120; h-index: 113, and I10-index: 993.

Vivekanand Singh is a professor at the Department of Civil Engineering and has 28 years of experience in the field of river hydraulics, groundwater and water resources engineering. Dr. Singh has published research papers in international journals including ASCE Journal. He has done national projects and consultancy during his work at NIT Patna. Prior to this, Dr. Singh was Scientist at National Institute of Hydrology Roorkee. He organized several summer courses, conferences and workshops. He has been working as Editor in some Indian Journals.

L. B. Roy is a professor at the Department of Civil Engineering and has 33 years of experience in the field of water resources engineering as well as geotechnical engineering. Dr. Roy has been serving the Water Resources Engineering Department for long time and carried out various field based research activities for different river systems of the region with special emphasis to floods. Dr. Roy has been involved in many research projects and published several research papers in peer reviewed journals. He has been working for intellectual property rights (IPR) and received awards for various activities.

Roshni Thendiyath is an assistant professor at the Department of Civil Engineering and has nine years of experience in the field of water resources engineering. Dr. Roshni earned her Ph.D. in Civil Engineering at the University of Pisa, Italy. After obtaining Ph.D., Dr Roshni had joined National Institute of Technology Calicut, India, as an ad-hoc faculty and later joined National Institute of Technology Patna as an assistant professor. She has supervised 2 Ph.D., more than 30 Master theses. Furthermore, she has been awarded DST-SERB project for the topic Two Phase Flows and Water Quality in Rivers, funded by the Department of Science and Technology, MHRD India. Results obtained from her research have been published nearly 30 papers in international journals and more than 15 papers in international conferences and three book chapters. Dr. Roshni is active in a variety of professional bodies and she has organized numerous workshops and conferences in her academic career.

Establishing Sediment Rating Curves Using Optimization Technique

Mohammad Zakwan and Zeenat Ara

1 Introduction

Deposition of sediment transported by a river is an important aspect of water resource engineering. Water resource projects is affected by the amount and concentration of sediment transported by a river as it results in reduction of reservoir capacity (Zakwan et al. 2017a; Ara and Zakwan 2018; Pandey et al. 2020). Therefore, quantification of sediment volume is required for estimation of design life of reservoirs and river training (Nagy et al. 2002; Muzzammil et al. 2018; Zakwan et al. 2018).

In the past, several attempts were made to correlate the sediment load and different flow properties such as discharge, velocity, precipitation and friction factor. Investigating uncertainties related to sediment transport curves, it has been found that accuracy of estimated sediment concentrations is largely dependent on the method used for fitting the sediment-rating curve. Therefore, the fundamental challenge in estimating sediment load is to select an appropriate curve fitting method and to determine the accuracy with which that technique fits the observed data. Ferguson (1986) pointed out that linear regression of logarithmic transformed sediment rating curve introduces a bias in the estimates of sediment load which may lead to underestimation of sediment load by as much as 50%. Asselman (2000) developed sediment rating curves using linear regression with and without a correction factors and concluded that they underestimate sediment loads. Demissie et al. (2004) too suggested nonlinear regression as better approach to estimate sediment load rather than linear regression which underestimates sediment load as observed by them for several streams in Illinois. Therefore, several researchers have turned towards the machine learning and non-linear optimization techniques to estimate sediment load.

Jain (2001) utilized the Artificial Neural Network (ANN) approach to establish the stage discharge-sediment relationship. Nagy et al. (2002) used ANN to model

---

M. Zakwan · Z. Ara (✉)
Civil Engineering Department, MANUU, Hyderabad 500032, India
e-mail: zeenatiitd@rediffmail.com

R. Jha et al. (eds.), *River and Coastal Engineering*, Water Science
and Technology Library 117, https://doi.org/10.1007/978-3-031-05057-2_1

sediment concentration with various inputs and demonstrated that ANN models are more reliable than the conventional models. Most commonly used neural network, multi-layer perceptron (MLP), was used by Kisi (2004) for more accurate estimation of suspended sediment concentration as compared to multiple linear regression. Sakai et al. (2005) applied multi-objective optimization technique to model suspended sediment concentration curves. Crowder et al. (2007) used nonlinear optimization technique for developing sediment rating curves for several gauging sites. They suggested that regression technique that would yield best rating curve would depend on the shape and variability of sediment–discharge relationship, the amount of data used for calibrating the equation and the time frame over which sediment load is to be estimated. Lohani et al. (2007) proposed the concept of developing integrated stage–discharge–sediment relationship using fuzzy logic. Following a similar approach, Jain (2008) tested the capabilities of compound neural networks by developing the integrated stage discharge sediment rating curves. Based on coefficient of correlation and sum of square of error statistics Jain (2008) concluded that CNN consisting of two network can model the rating curve more accurately than single artificial neural network. Aytek and Kisi (2008) developed sediment rating curves using Genetic programming (GP) and demonstrated the superiority of GP over traditional rating curves. Cobaner et al. (2009) estimated the suspended sediment concentration using adaptive neuro-fuzzy approach with discharge, rainfall and sediment data of different periods as an input. Comparing the results of multi-layer perceptron (MLP), generalized regression neural networks (GRNN), the radial basis neural networks (RBNN) and sediment rating curves (SRC) with the adaptive neuro-fuzzy approach they reported neuro-fuzzy approach estimates the sediment concentration more accurately. Reddy and Ghimire (2009) demonstrated the superiority of Model Tree M5 over simple sediment rating curve, multi-linear regression and Gene Expression Programming. Kumar et al. (2012) compared ANN with back propagation and Levenberg-Merquardt algorithms, radial basis function, Fuzzy Logic, and decision tree algorithms M5 and REPTree to model sediment concentration and reported model tree M5 as the better approach among them to model sediment rating curves. It has also been reported that Genetic Algorithm (GA) is more reliable approach than model tress (MT) in developing rating curves as demonstrated by Ghimire and Reddy (2010) in case of discharge rating curves. Recently, Zakwan et al. (2017a, b b) demonstrated that GRG technique is as efficient as GA in case of discharge rating curve. In this regard, the present paper employs GRG technique to establish the sediment rating curves for two sites.

2 Materials and Method

In the present study daily sediment discharge data of two sites in USA has been used. The first data set correspond to a period of January 1, 1969–December 31, 1972 for Missouri river at Hermann, Missouri (site number: 6934500). Second data set correspond to a period of October 1, 1997–January 31, 2002 for Mississippi

Table 1 Statistical parameters of Sediment-discharge data

Data	Station	Quantity	Mean (μ)	Coefficient of variance	Max	Min
Calibration	Hermann	Discharge (m^3/s)	2551	0.59	9995	467
		SSL (ton/d)	245,039	1.45	2,010,000	3120
	Grafton	Discharge (m^3/s)	3303	0.65	10,081	830
		SSL (ton/d)	66,617	1.16	43,300	5080
Validation	Hermann	Discharge (m^3/s)	2133	0.42	6286	572
		SSL (ton/d)	169,027	0.99	94,900	9330
	Grafton	Discharge (m^3/s)	3873	0.70	10,363	977
		SSL (ton/d)	38,016	1.03	197,000	4590

river below Grafton, Illinois (site number: 5587455). These data sets are available on USGS website[1]. The salient features of the data set are reported in Table 1.

Continuous measurement of sediment load is very costly and impractical especially in large rivers, therefore, in majority of the rivers, sediment loads are generally estimated by indirect means of developing a relation between discharge and sediment load (Zakwan et al. 2021). This relationship is generally expressed as:

$$S = a(Q)^b \tag{1}$$

where S = SSL in ton/day; Q = discharge in m^3/s; a and b are regression coefficients.

Conventionally, the regression coefficients are estimated by using the linear regression method involving logarithm transformation of Eq. (1), but such transformation introduces a bias in the estimates as pointed out earlier therefore, the present paper presents the use of nonlinear optimization techniques to estimate these regression coefficients.

In the present study daily sediment discharge data sets of two sites i.e. Hermann site on Missouri river and Grafton site on Mississippi river was used. From these data sets 75% of the data set was randomly used for the calibration and 25% was used for validation. In the calibration period SSL discharge data was utilised to establish the sediment rating curve using conventional method (RM) and GRG technique. To obtain the optimal relation between SSL and discharge, sum of square of deviation between calculated SSL and estimated SSL was set to minimization defined as

$$\text{Min SSE} = \sum_{i=1}^{N} [X_i - Y_i]^2 \tag{2}$$

where X_i is calculated SSL; Y_i is predicted SSL. The details of optimization tools used in the present study are as follows.

---

[1] (cida.usgs.gov/sediment)

3 GRG Technique

GRG technique is a non-linear optimization code developed by L. S. Lasdon, A. D. Waren, A. Jain and M. Ratner in FORTRAN language (1978). Lasdon et al. (1978) modified the earlier work of Abadie and Carpentier (1969) on GRG technique. GRG technique integrates the function of graphical user interface (GUI), algebraic modelling languages like AMPL or GAMS and optimizers of linear, non-linear and integer programs. It is nonlinear extended version of simplex method. GRG technique involves either of the two techniques viz. Quasi-Newton method or Conjugate Gradient method for determination of the search direction (Zakwan 2017).

Jewell (2001) demonstrated the application of TK solver in handling the hydraulic design problems. Karahan (2009) proposed the use of GRG technique, to estimate the parameters of linear form of Muskingum flood routing equation. Barati (2013) demonstrated the superiority of excel solvers over Immune clonal selection algorithm (ICSA) and Genetic algorithm (GA) in estimating the outflow using nonlinear Muskingum flood routing equation. Stage discharge relationship was established by using GRG technique by Muzzammil et al. (2015) and Muzzammil et al. (2018). Zakwan et al. (2016) used GRG technique for estimating parameters of infiltration models. Zakwan and Muzzammil (2016) applied GRG technique for estimating the parameters of nonlinear Muskingum model.

4 Results and Discussion

In the present study daily sediment discharge data of two sites was used. From these data sets 75% of the data sets were used for the calibration and 25% were used for testing. In the calibration period SSL discharge data was utilised to establish the sediment rating curve using conventional regression analysis. Further, the relationship between SSL and discharge was also established using GRG nonlinear optimization techniques.

The parameters of sediment rating equation as obtained by regression and nonlinear optimization method for the two sites under consideration have been reported in Table 2. Kumar et al. (2012) reported model tree M5 as the better approach

Table 2 Sediment rating curve parameters

Station	Method	a	b
Hermann	RM	0.0043	2.226
	GRG	0.176	1.785
Grafton	RM	0.0337	1.751
	GRG	0.841	1.386

among them to model sediment rating curves. Ghimire and Reddy (2010) demonstrated that Genetic Algorithm (GA) is more reliable approach than model tress (MT) in developing discharge rating curves. Spreadsheet based approach (GRG technique) has been found as efficient as GA, however, the simplicity of GRG technique is an advantage over GA.

The SSL estimated by regression method and non-linear optimization were compared based on following criteria.

$$\text{Root mean square (RMSE)} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{N}} \quad (3)$$

$$\text{Correelation coefficient} = \frac{N\left(\sum XY\right) - \left(\sum Y\right)\left(\sum X\right)}{\sqrt{\left(N\left(\sum (Y^2)\right) - \left(\sum Y\right)^2\right)\left(N\left(\sum X^2\right) - \left(\sum X\right)^2\right)}} \quad (4)$$

$$\text{Nash coefficient} = \left[1 - \frac{\sum_{i=1}^{N} (X_i - Y_i)^2}{\sum_{i=1}^{N} (X_i - \overline{X})^2}\right] \quad (5)$$

where X_i is calculated SSL corresponding to any discharge; Y_i is predicted SSL corresponding to any discharge.

The results of comparative analysis are reported in Tables 3 and 4, which demonstrate that the application nonlinear optimization techniques result in lower root mean square error, values of Nash efficiency and correlation coefficient closer to unity as compared to those obtain by regression analysis for both calibration and validation in either case. Therefore, it may be inferred that sediment discharge rating estimated by using nonlinear optimization techniques are more reliable (Fig. 1).

Table 3 Performance indices during calibration

Station	Method	RMSE	Nash coefficient	Correlation coefficient
Hermann	RM	169,315	0.77	0.90
	GRG	137,704	0.85	0.99
Grafton	RM	43,000	0.68	0.83
	GRG	41,003	0.82	0.99

Table 4 Performance indices during validation

Station	Method	RMSE	Nash coefficient	Correlation coefficient
Hermann	RM	82,692	0.76	0.89
	GRG	71,191	0.83	0.99
Grafton	RM	95,555	0.75	0.85
	GRG	86,948	0.80	0.99

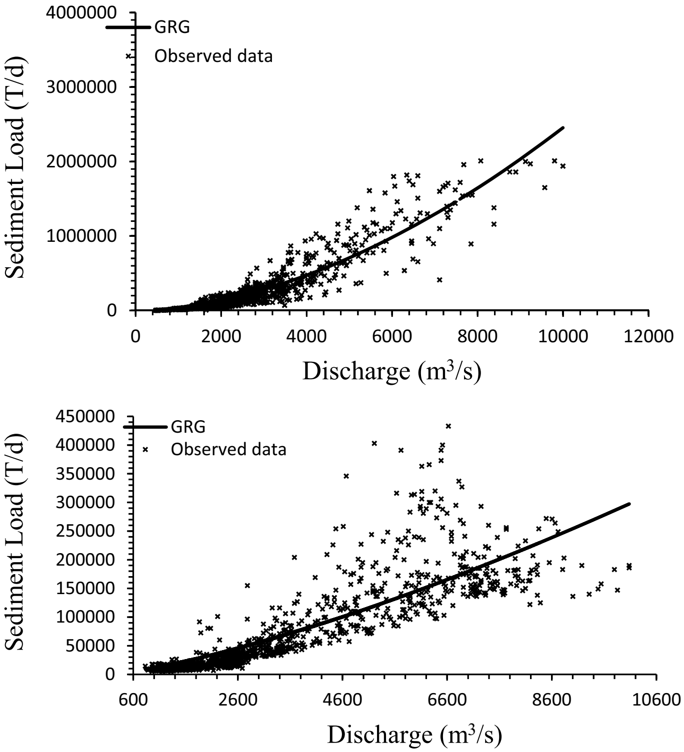

Fig. 1 Sediment load curve for Hermann and Grafton gauging sites

5 Conclusion

The sediment rating curves were established using conventional regression method and nonlinear optimization method for the two different sites. The performance of both the methods was assessed using different fitness criteria's. It has been found that nonlinear optimization approach is more reliable than the regression analysis for estimating the sediment rating parameters. Results also demonstrate that GRG technique is a powerful, simple and promising tool for nonlinear optimization. Even without utilising complicated programming techniques they can be used as an efficient optimization tool in the field of water resource engineering. Unlike most of the soft computing techniques application of GRG technique does not obscure theoretical background of the problem therefore, it can be helpful in teaching various problems involving optimization.

References

Abadie J, Carpentier J (1969) Generalization of the Wolfe reduced gradient method to the case of nonlinear constraints. Optimization. Academic Press, New York, p 37–47

Ara Z, Zakwan M (2018) Reservoir sedimentation analysis: a case study. In: Proceedings national conference on water, environment & society (NCWES-2018). Hyderabad, India p 286–292

Asselman NEM (2000) Fitting and interpretation of sediment rating curves. J Hydrol 234:228–248

Aytek A, Kisi O (2008) A genetic programming approach to suspended sediment modelling. J Hydrol 351:288–298

Barati R (2013) Application of excel solver for parameter estimation of the nonlinear Muskingum models. KSCE J Civ Engg 17(5):1139–1148

Cobaner M, Unal B, Kisi O (2009) Suspended sediment concentration estimation by an adaptive neuro-fuzzy and neural network approaches using hydro-meteorological data. J Hydrol 367(1–2):52–61

Crowder DW, Demissie M, Markus M (2007) The accuracy of sediment loads when log-transformation produces nonlinear sediment load—discharge relationships. p 250–268. https://doi.org/10.1016/j.jhydrol.2006.12.024

Demissie M, Xia R, Keefer L, Bhowmik N (2004) The sediment budget of the Illinois river. Illinois State Water Survey, Contract Report 2004–13. Champaign, IL

Ferguson RI (1986) River loads underestimated by rating curves. Water Resour Res 22(1):74–76

Ghimire BNS, Reddy MJ (2010) Development of stage-discharge rating curve in river using genetic algorithms and model tree. Int Workshop Adv Stat Hydrol. Taormina, Italy

Jain SK (2001) Development of integrated sediment rating curves using ANNs. J Hydrol Engg 13(3):124–213

Jain SK (2008) Development of integrated discharge and sediment rating relation using a compound neural network. J Hydrol Eng 13(3):124–131

Jewell TK (2001) Teaching hydraulic design using equation solvers. J Hydrol Engg 0733–9429/127(12):1013–1021

Karahan H (2009) Predicting Muskingum flood routing parameters using spreadsheet. Wiley Periodicals Inc., p 280–286

Kisi O (2004) Multi-Layer perceptrons with Levenberg-Marquardt training algorithm for suspended sediment concentration prediction and estimation. Hydrol Sci J 49(6):1025–1040

Kumar ARS, Ojha CSP, Goyal MK, Singh RD, Swamee PK (2012) Modelling of suspended sediment concentration at Kasol in India using ANN, fuzzy logic, and decision tree algorithms:394–404. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000445

Lasdon LS, Waren AD, Jain A, Ratner M (1978) Design and testing of a generalized reduced gradient code for nonlinear programming. ACM Trans Math Softw 4(1):34–50

Lohani AK, Goel NK, Bhatia KKS (2007) Deriving stage discharge-sediment concentration relationships using Fuzzy logic. Hydrol Sci J 52(4):793–807

Muzzammil M, Alam J, Zakwan M (2015) An optimization technique for estimation of rating curve parameters. Nat Symp Hydrol 234–240

Muzzammil M, Alam J, Zakwan M (2018) A spreadsheet approach for prediction of rating curve parameters. In: Singh V, Yadav S, Yadava R (eds) Hydrologic modeling. water science and technology library, vol 81. Springer, Singapore

Pandey M, Zakwan M, Khan MA, Bhave S (2020) Development of scour around a circular pier and its modelling using genetic algorithm. Water Supply 20(8):3358–3367

Nagy HM, Watanabe K, Hirano M (2002) Prediction of sediment load concentration in rivers using artificial neural networks. J Hydrol Eng 128(6):588–595

Reddy MJ, Ghimire BNS (2009) Use of Model tree and Gene expression programming to predict the suspended sediment load in rivers. J Intell Syst 18(3):211–227

Sakai K, Osawa K, Yoshinaga A (2005) Development of suspended sediment concentration (SSC) analysis model and its application with multi-objective optimization. Paddy Water Environ 3:201–209

USGS website, cida.usgs.gov/sediment

Zakwan M, Muzzammil M (2016) Optimization approach for hydrologic channel routing. Water Energ Int 59(3):66–69

Zakwan M, Muzzammil M, Alam J (2016) Application of spreadsheet to estimate infiltration parameters. Perspect Sci 8:702–704

Zakwan M (2017) Assessment of dimensionless form of Kostiakov model. Aquademia Water Environ Technol 1(1):01

Zakwan M, Muzzammil M, Alam J (2017a) Application of data driven techniques in discharge rating curve-an overview. Aquademia 1(1):02

Zakwan M, Muzzammil M, Alam J (2017b) Developing stage-discharge relations using optimization techniques. Aquademia Water Environ Technol 1(2):05

Zakwan M, Ahmad Z, Sharief SMV (2018) Magnitude-frequency analysis for suspended sediment transport in Ganga river. J Hydrol Engg https://doi.org/10.1061/(ASCE)HE.1943-5584.0001671

Zakwan M, Pham QB, Zhu S (2021) Effective discharge computation in the lower Drava River. Hydrol Sci J:1–12

A Study on Some Characteristics of an Alluvial Channel for Varying Flows

Mayuraksha Bardhan

1 Introduction

The object of the present study is to gather some qualitative knowledge on some characteristics of alluvial channels when their patterns undergo a continuous change to straight or meandering or combination of both due to the interaction of a particular bed material and two different discharges flowing on these channels for a definite period of time to obtain them into regime conditions. An attempt has also been made here to find the effect of inclusion of a river training structure on those regime channels.

2 Literature Study

Chatterjee (1987) discussed about movable bed hydraulic model for studying morphological problems and various constraints in obtaining reliable results from those studies. Ghosh (1987) discussed about effect of meandering and fluming on alluvial channels. Ghosh and Bose (1989) made a study on some characteristics of an alluvial channel. Langbein and Leopold (1966) made extensive studies on the fluvial processes in rivers by using prototype data and physical model. The effect of meandering and width of the alluvial channel on the friction factors and sediment transport capacity had been investigated by Onishi, Jain and Kennedy (1976). Emmett, Leopold and Myrick (1983) made extensive study on some characteristics of fluvial processes. The effect of overall deformation of beds of curved alluvial channels on flow characteristics in a smooth rigid-bed meandering channel had been

---

M. Bardhan (✉)
River Research Institute, P.O.-Haringhata, R.R.I, Nadia, West Bengal 741246, India
e-mail: mayur.bardhan@gmail.com

R. Jha et al. (eds.), *River and Coastal Engineering*, Water Science
and Technology Library 117, https://doi.org/10.1007/978-3-031-05057-2_2

studied by Yen (1970). In spite of the above studies about the fluvial processes in rivers, many short comings still remain in understanding the processes.

3 Experimental Set-Up

Experiments were conducted during the year 1997. An experimental alluvial channel of 300 ft (91.44 m) in length with a trapezoidal cross section of 4 inch (10 cm) in depth, 4 inch (10 cm) bed width and side slope 2: 1 (as shown in Fig. 1) was laid on a sand tray of 300 ft (91.44 m) in length and 30 ft (9.144 m) in width.

The initial slope of the channel was introduced as 0.003 and the size of the bed material was taken as $D_{50} = 0.332$ mm. At the entrance of the channel, an initial curvature was introduced to accelerate the meandering process of the channel. At first, under this condition, a steady flow of discharge 0.003 cumecs (Q1) was circulated through the experimental straight channel for a period of 150 h when a regime channel was obtained on the basis of observation of the steadiness of channel slope and channel morphology, taken at every 50 h interval. It was noticed that only three successive meanders of about same length had developed up to a distance of 120 ft (36.576 m) along the longitudinal direction of the channel. The rest portion of the channel remained straight.

At this stage, a river training structure (like barrage) was introduced at a section of 56 ft (17.069 m) from the entrance of the channel. The opening of waterway downstream of the barrage was allowed at 30% and thus a horizontal fluming of the order of about 70% was introduced on the regime channel. Under this condition and with the same discharge, the flume was again allowed to run for a period of 150 h until a regime channel was again supposed to have attained. The experiment

Fig. 1 View of the experimental alluvial channel

was repeated in the same process with another discharge of 0.007 cumecs (Q2). The regime channel thus formed is supposed to have composed of two major reaches, meandering reach with or without a structure and straight reach with or without a structure.

4 Analysis of Data

The data obtained from the experimental channel under two varying discharges (Q1 & Q2) are analyzed and presented here.

4.1 Fluvial View

The net changes in the cross sectional flow areas for two different discharges Q1 & Q2 along the longitudinal direction of the channel are shown graphically in Fig. 2.

The curve showing separately the net change in cross sectional area- scour or filling between two flows have also been presented in the upper portion of the same figure. Here the scour is assumed when the flow area for Q2 is greater than that for Q1 and filling is assumed when the flow area for Q2 is smaller than that for Q1. It is clear that in the meandering reach flow areas for each discharge varies remarkable in the same pattern and there also exists a considerable scour through out the reach. However, in

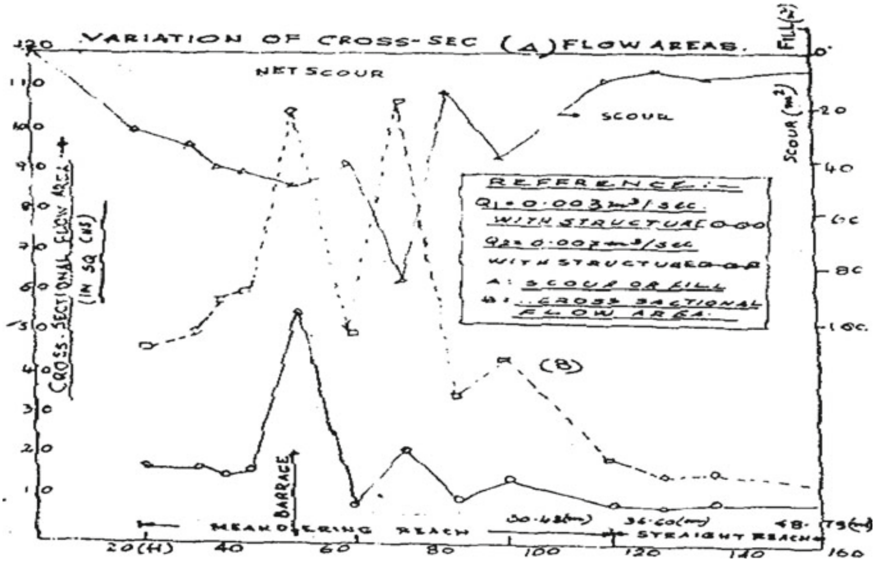

Fig. 2 Changes in cross sectional flow areas for two different discharges

the straight reach, the variation of flow areas for each discharge is not so perceptible though throughout most part of this reach, there is scouring process to some extent. It can be stated from this figure that in the meandering reach, considerable scour is always associated with the increase of discharge and no systematic correlation between scour and increase or decrease of flow areas can be obtained.

Figure 3 presents the elevation of deepest points of the channel in longitudinal direction. Here the deepest point alternatively rises or falls for each discharge but it is always higher in the discharge Q2 than that in the discharge Q1 in both the reaches. Figure 4 shows the elevation of mean depth of the channel. Here also same phenomenon is noticed. Hence from Figs. 2, 3 and 4, it can be stated that any considerable scour which occurs has got no correlation with the elevation of deepest point or mean depths of the channel.

Figures 5 and 6 represent the profiles of total bed width (W) and water surface width (B) of the channels for two different discharges Q1 and Q2 respectively. It appears from these figures that both total bed width and water surface width increase considerably with the increase of discharge in the meandering reach of the channel and this phenomenon is more in case of total width of the channel.

In the straight reach, both total width and water surface width increase due to increase of discharge but this is significantly smaller than that observed in the meandering reach. From these facts, it can be inferred that the considerable scour that always occurs with increase of discharge in the meandering reach may be associated

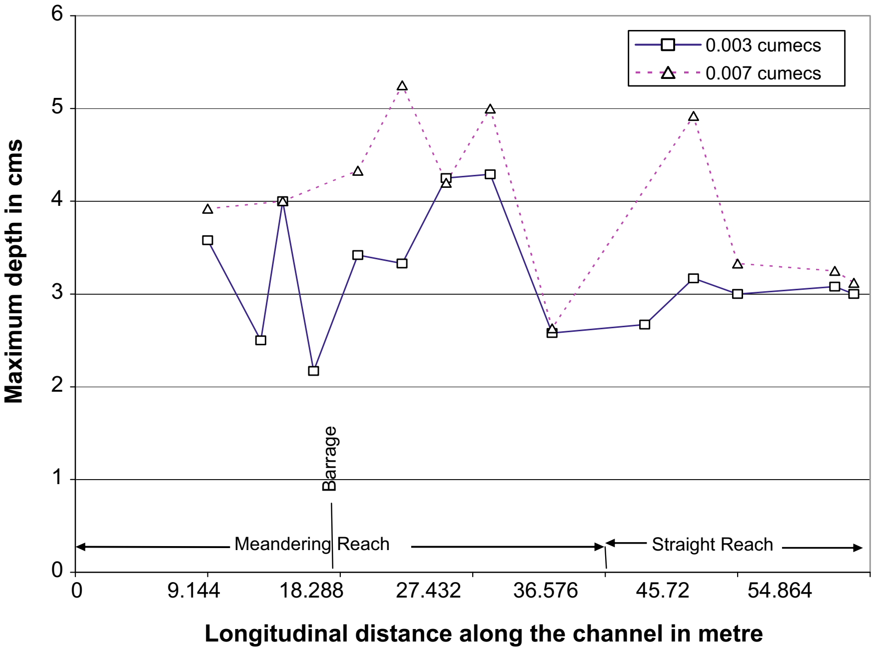

Fig. 3 Maximum depth along channel after 150 h of model run

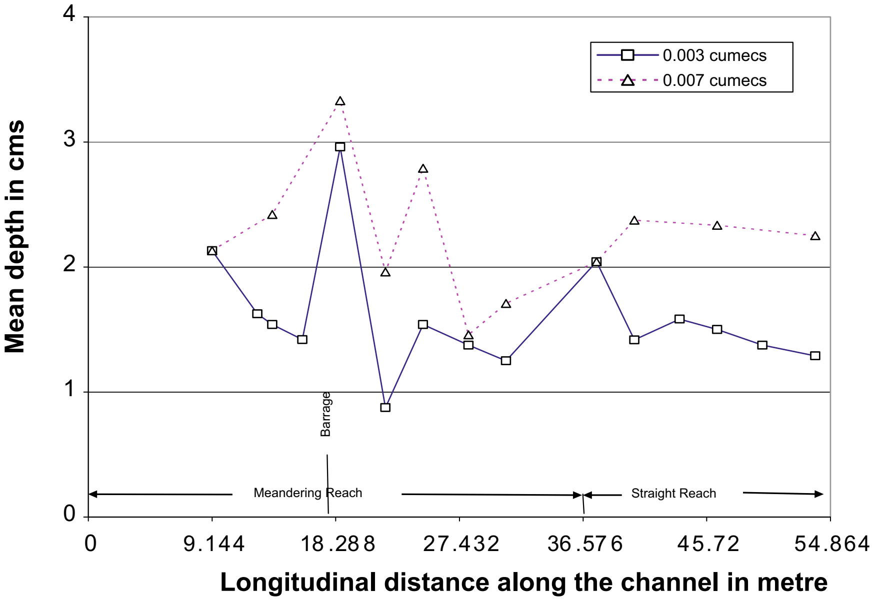

Fig. 4 Mean depth along channel after 150 h of model run with structure (barrage)

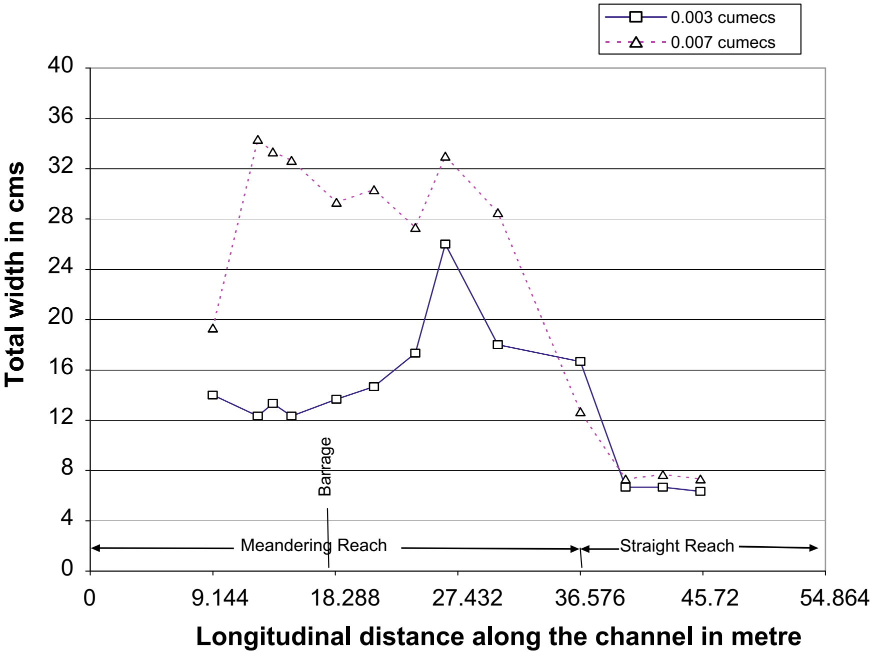

Fig. 5 Variation of bank width along the channel at different discharges (with barrage)

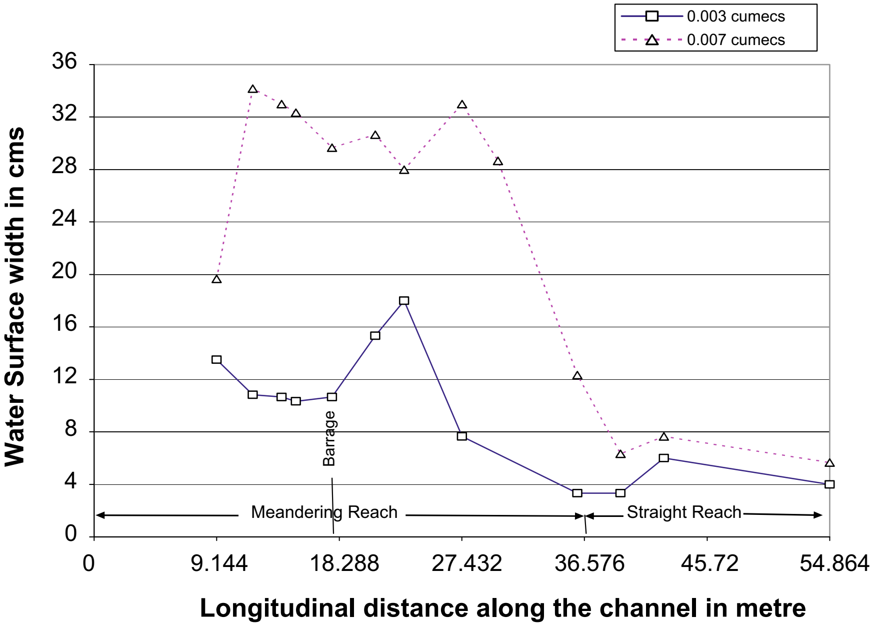

Fig. 6 Variation of water surface width along the channel (with barrage)

with the increase in total width or water surface width and as such there may exist a good correlation between scour and total width or water surface width in this reach. The absolute magnitude of flow area and total surface width as shown in Fig. 2 may not reveal the real effect of flow phenomenon, the relative increase in flow areas and total surface width for two flows would describe more accurately the effect that happens. The upper and lower part in the Fig. 7 represents respectively the relative changes in the flow areas and the total surface width (W) for two flows. It appears from these curves that with the change of total surface width, the cross-sectional flow areas also change and in the upstream of the barrage, the variation in total width (W) is wide and higher than variation in cross- section but at the downstream of the barrage, it is reverse.

4.2 Analytical View

For alluvial channels undergoing changes, the total rate of energy expenditure or power expenditure of a channel reach at an instant is defined as:

$$P = \int_{\gamma}^{m} Q\, S\, X\, dx \tag{1}$$

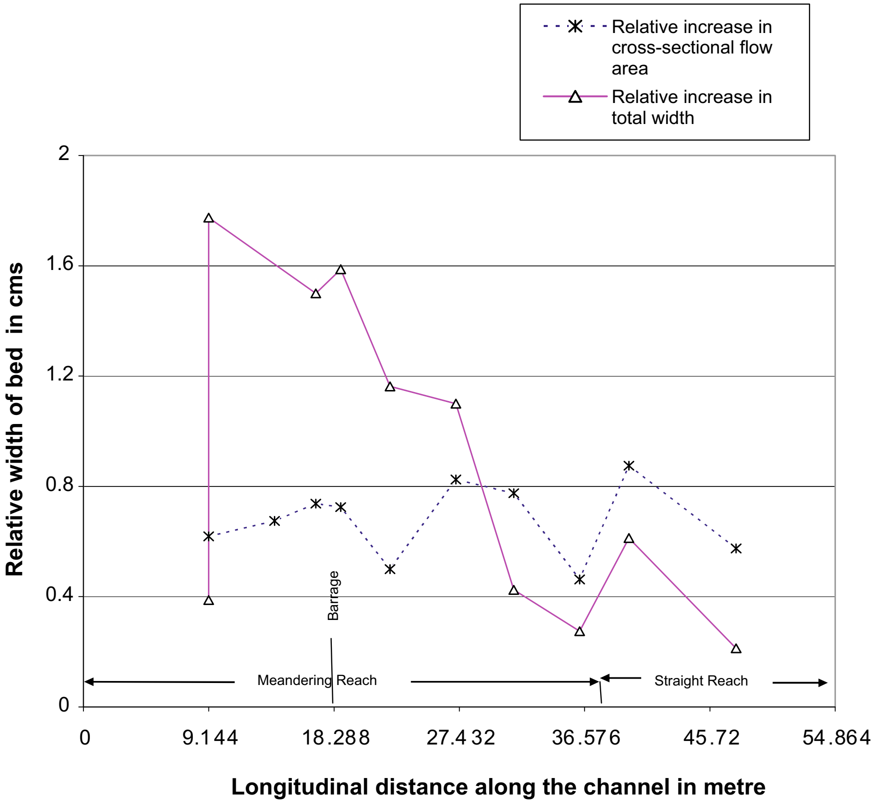

Fig. 7 Relative increase in total bed width and cross-sectional flow area

where P is total stream power of a reach in energy / time, γ is specific weight of water, m is length of the reach, Q is discharge, X is distance along flow direction and S is energy gradient. Any changes in the pattern of these channels reflect the changes of resistance to flow or in power expenditure.

The curves in Fig. 8 reflect the power expenditure of two regime channels obtained for two flows Q1 and Q2. It appears from these curves that in the meandering reach, power expenditure increases slowly and in the straight reach, it is almost uniform.

Again from Figs. 2, 3, 4, 5, 6 and 7, it appears that any change in the channel morphology is associated with the increase of channel surface width or total width which is usually accompanied by a variation in flow resistance or power expenditure. Then it can be inferred that any adjustment of the channel morphology for becoming a regime channel is closely related to the change in power expenditure. Figures 9, 10, 11 and 12 depict the sequential changes in the cross-sectional profiles.

The curves in Figs. 9 and 10 represent the sequential variation of two cross-sections under two different discharges Q1 & Q2 at 10.97 m and 14.02 m upstream of the barrage in the meandering reach. It appears from both the figures that water

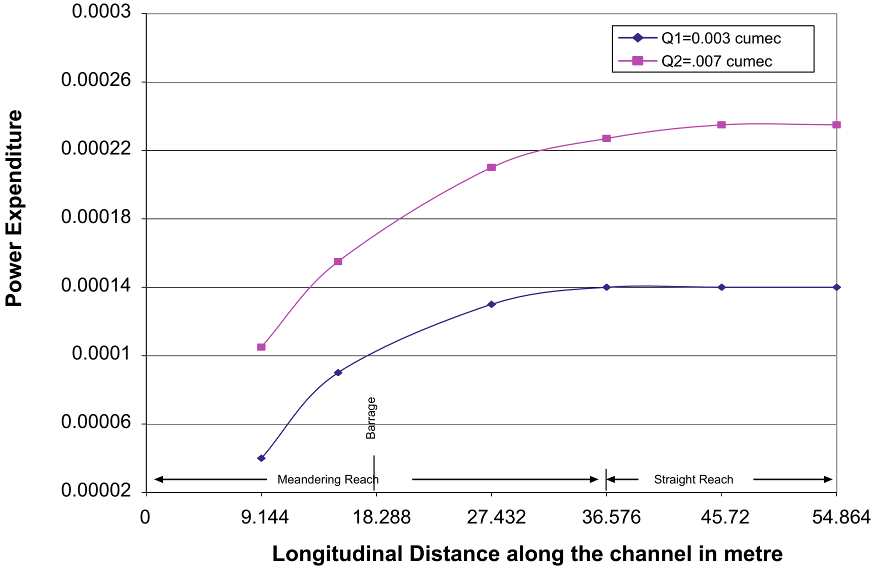

Fig. 8 Power expenditure along the channel for two different flow conditions

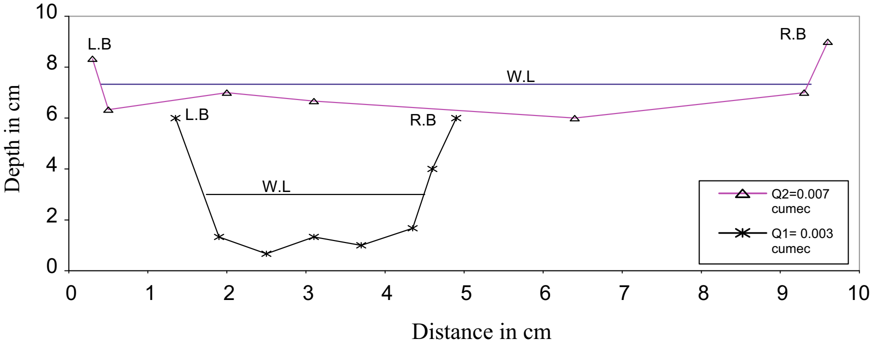

Fig. 9 Changes in cross-section of the channel at 10.97 m u/s of barrage in meandering reach

surface or total bed width increased and the bed is elevated. Figure 11 represents the same at 27.43 m downstream of the barrage in the meandering reach of the channel and the same phenomenon is observed here also. Figure 12 represents the sequential variation of cross-section 44.2 m downstream of the barrage in the straight reach. Here it is observed that bed of the channel is depressed and the water surface or total bed width increases.

From all Figs. 9, 10, 11 and 12, it can be said that with increase in discharge, water surface or total bed width of an alluvial channel increases and is accompanied by increase in boundary resistance or power expenditure.

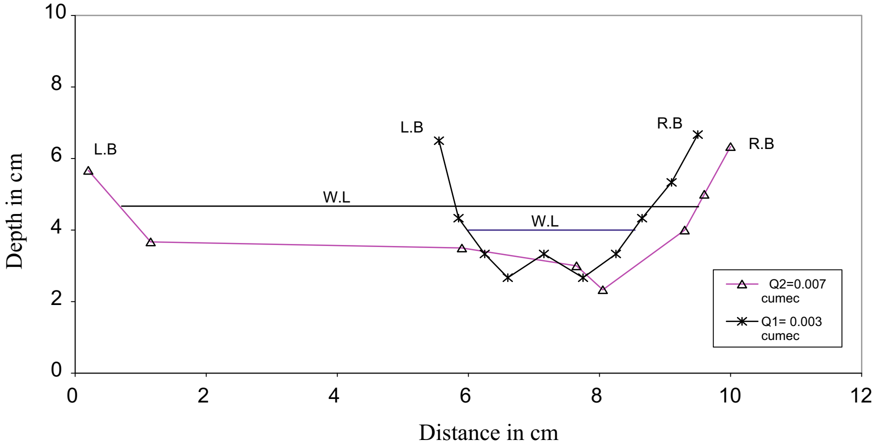

Fig. 10 Changes in cross-section of the channel at 14.02 m u/s of barrage in meandering reach

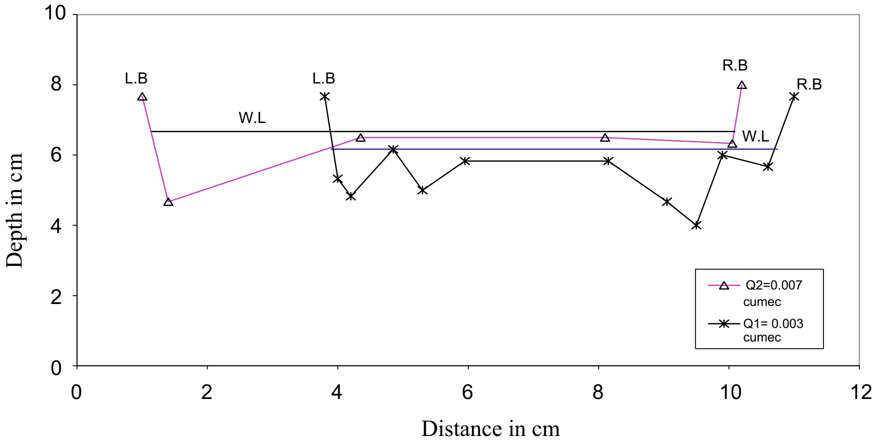

Fig. 11 Changes in cross-section of the channel at 27.43 m d/s of barrage in meandering reach

5 Conclusions

From the analysis of the experimental data, it may be concluded that in the meandering reach of an alluvial regime channel, any change in cross-sectional flow area is associated with the increase of water surface width or total bed width which is again accompanied by the increase in boundary resistance or power expenditure. As such, there may be a good correlation between scour and increase of water surface or total bed width and hence to power expenditure in the meandering reach of an alluvial regime channel. But it may not exist in the straight reach of the same channel.