

**NUMERICAL MODELING OF SEDIMENT DEPOSITION
IN HEADWATER RESERVOIRS**

by

Poonam Binjolkar

Submitted

in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the



**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
NEW DELHI-110016, INDIA**

November 2008

Dedicated to

my Father

Late Sh. S. L. Vaidya

CERTIFICATE

This is to certify that the thesis entitled **NUMERICAL MODELING OF SEDIMENT DEPOSITION IN HEADWATER RESERVOIRS** submitted by Ms. Poonam Binjolkar to the Indian Institute of Technology Delhi for the award of Doctor of Philosophy in Department of Civil Engineering, is a record of bonafide research work carried out by her under my supervision and guidance.

The thesis work in my opinion has reached the requisite standard, fulfilling the requirements for the said degree. The results contained in this thesis have not been submitted, in part or full, to any other university or Institute for the award of any degree or diploma.



(Ashok K. Keshari)
Associate Professor
Department of Civil Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi 110016, India

ACKNOWLEDGEMENT

I feel immense pleasure in expressing my great sense of gratitude and heart felt thanks to Dr. Ashok Kumar Keshari, Department of Civil Engineering, Indian Institute of Technology, Delhi, New Delhi for his invaluable and sincere guidance. I am indebted to him for his continuous and constructive encouragement during the course of work reported in this thesis. His inspiration and kind encouragement were of great help in completing the present research work.

I wish to extend my sincere thanks to all faculty members of the Water Resources Engineering, Department of Civil Engineering, I. I. T. Delhi, New Delhi for their co-operation.

I am sincerely thankful to Mr. E. Sunderaiya, Chief Engineer (Retd.) Central Water Commission for his invaluable guidance and help in data collection. I am also thankful to Mr. Tirathram, Manager, RITES Ltd. and Mr. Pankaj Tanwar for their help in help in the present work.

I am sincerely thankful to “The Chairman”, Himachal Pradesh State Electricity Board (HPSEB) for permitting me to pursue this research.

I also thank Mr. M. J. Kaledhonkar, Mr. Dhiman, Mr. D. Parmar, Mr. S. Y. Rao and Mr. Satpathi. Thanks are also due to Mr. Vikram, Mr. Rajveer Agarwal and Mr. Narender.

I wish to offer my gratitude to my Parents-in-law. Their support and encouragement is sincerely appreciated.

I owe a great deal to my parents for their love and encouragement to pursue my interests. Without their initial momentum and continuous support from my mother, it would have not been possible for me to achieve my goal. I am also indebted to my sister Asha Kapoor and brothers Naresh Vaidya and Umesh Vaidya for their moral support and continuous encouragement.

I reserve my deepest gratitude for my husband Col Ashok Kumar Binjolkar and two loving daughters Mayuree and Manjaree for their patience, unselfish devotion, moral support and continual encouragement throughout my research work.

Last but not the least, I thank Almighty for helping me in achieving my goal.


POONAM BINJOLKAR

ABSTRACT

The accurate assessment of sedimentation is essential to ascertain the viability of a river basin project as incorrect assessment of the rate of sedimentation and deposition pattern within the reservoirs may undermine the very existence of the dam/reservoir. Geomorphological parameters of the reservoir catchment, flow conditions and reservoir regulation influence the deposition of sediments within the reservoirs. A methodology consisting of determination of geomorphological parameters using GIS, a hydrological water balance model for determining water levels on 10-daily and monthly basis in a reservoir, a 2-D hydrodynamic model for flow investigation and a 2-D sediment transport model for investigating sediment deposition pattern within reservoirs is presented for qualitative and quantitative assessment of reservoir sedimentation. The hydrodynamic model incorporates the effect of turbidity currents and plunging phenomenon. The sediment transport model consists of two sub models, namely, suspended sediment transport and bed load transport models, and accounts for the cohesiveness character of sediment and the change in bed profile. Solutions were obtained numerically using the MacCormack two step predictor corrector scheme for the hydrodynamic model and the upwind scheme for the suspended sediment transport model. The capability of these models have been demonstrated with the application of developed models to the Tilaiya and the Tenughat reservoirs, the headwater reservoirs of the Damodar river basin. Results reveal good agreement for sediment deposition within the reservoirs generally having R^2 value of 0.9 and above for the sediment bed level in case of both the reservoirs.

The analysis of various geomorphological parameters namely, length, area, perimeter, drainage density, drainage frequency, basin circularity, basin elongation, relief, ruggedness number, Shape index, Gravelius index using GIS for the Tilaiya and

the Tenughat reservoir catchments reveals that the Tilaiya catchment is elongated drainage basin with low drainage density, whereas the Tenughat catchment is comparatively less elongated with low basin elongation and higher circulation. It appears that there is some influence of geological structures in its lower reaches. The upper reaches covering low order streams with comparatively low bifurcation ratio appear to be rocky and less susceptible to erosion. The error associated with the values obtained for various geomorphological parameters is restricted up to 5%.

The hydrodynamic model provides various flow parameters such as the flow field and the depth as input to the sediment transport model. The model was calibrated by adjusting the Manning's roughness coefficient. The changes in bottom roughness due to cohesive and noncohesive sediments were accounted for by varying the roughness coefficient in different zones of the reservoir. Model results agree closely with the observed values of water level. The hydrological mass balance model was utilized for obtaining 10-daily and monthly water level variations. These water levels were used in hydrodynamic model for calibrating model parameter and as an input to the suspended sediment transport model.

The sediment transport model comprising suspended sediment transport and bed load transport models, yields reliable results in predicting the sediment transport and bed level changes across the reservoir bed. The study demonstrates that the sediment deposition in reservoirs significantly depend on the hydraulic conditions in the reservoir and flow variables. The incoming sediment load, both suspended and bedload, cohesiveness of sediment particles and settling velocity of suspended sediments influence sediment deposition in reservoirs significantly. The two different approaches adopted for

settling velocities clearly demonstrates that the sediment deposition of cohesive sediments is well defined using median floc diameter approach as compared to the one based on particle size diameter. Further, spatial variation of critical shear stress is also established. The wide variation in eddy diffusivity has been observed to result in negligible variations in the bed profiles across the reservoir cross sections.

In case of cohesive sediments, the settling velocities though negligibly small, are found to increase with the concentration of cohesive sediments. The settling velocity increases with the concentration of cohesive sediments resulting in comparatively more deposition of these sediments. In case of Tilaiya reservoir, the sediment concentration being very less, the settling velocities of cohesive particles are very small, and thus has resulted in low deposition of these sediments.

Formation of turbidity currents have also been investigated and it has been found that no turbidity currents are formed in any of the two study reservoirs. However, some indication of development of such currents at maximum water level in Tilaiya reservoir with negligibly small sediment concentration establishes the fact that the turbidity currents are not generated only in those reservoirs which are on heavily sediment laden rivers, but also in reservoirs on rivers with low sediment condition. The main reason of non formation of the turbidity currents in these reservoirs may however, be attributed to the water level or the depth of flow and hence the topography of the reservoir.

CONTENTS

	Page
• CERTIFICATE	i
• ACKNOWLEDGEMENT	ii
• ABSTRACT	iv
• LIST OF FIGURES	xiii
• LIST OF TABLES	xvi
• LIST OF SYMBOLS	xviii
Chapter-1 INTRODUCTION	
1.1 Background	1
1.2 Scope of research	3
1.3 Objectives	5
1.4 Modeling unconformities	6
1.5 Thesis organization	7
—	
Chapter-2 LITERATURE REVIEW	
2.1 Geomorphology of the drainage basin	9
2.2 Empirical approach	12
2.2.1 Empirical formulae for sedimentation in Indian reservoirs	19
2.3 Mathematical models for sediment transport based on riverine conditions	21
2.4 Mathematical models for sediment transport based on turbidity currents	26

2.5	Commonly used software	30
2.5.1	HEC-6	30
2.5.2	RESSED Model	33
2.5.3	RESSASS Model	34
2.5.4	Mike 11 Model	35
2.6	Concluding remarks	35

Chapter-3 SEDIMENT TRANSPORT MECHANISM WITHIN RESERVOIR

3.1	Introduction	39
3.2	Sediment Transport Mechanism	39
3.2.1	Deltaic deposition	42
3.2.2	Deposition in quasi-homogeneous flow region	44
3.2.3	Deposition in turbidity currents region	45
3.3	Hydraulics of turbidity currents	47

Chapter-4 MODEL DEVELOPMENT

4.1	Modeling approach	49
4.2	Hydrological water balance model	51
4.3	Hydrodynamic model	52
4.3.1	Determination of plunge point	57
4.4	Sediment transport model	59
4.4.1	Suspended sediment transport	60
4.4.2	Bed load transport	61
4.5	Sediment deposition on reservoir bed	62
4.6	Computing deposits properties	63

4.6.1	Computation of deposition rates and settling velocities	63
4.6.2	Computing unit weight of deposits	67
4.6.3	Computation of deposited sediments with time	69
Chapter-5	NUMERICAL SOLUTION	
5.1	Solution of hydrodynamic model	71
5.1.1	Initial and boundary conditions	82
5.1.2	Convergence and stability conditions	83
5.2	Solution of suspended sediment transport model	84
5.2.1	Initial and boundary conditions	88
5.3	Flow chart for numerical solution	89
Chapter-6	MODEL APPLICATION	
6.1	Description of the study area	94
6.2	Zoning of reservoir domain	99
6.2.1	Zoning of Tilaiya reservoir	99
6.2.2	Zoning of Tenughat reservoir	100
6.3	Zone wise particle size variation	112
6.3.1	Paricle size variation in Tilaiya reservoir	112
6.3.2	Particle size variation in Tenughat reservoir	114
Chapter-7	RESULTS AND DISCUSSION FOR TILAIYA RESERVOIR	
7.1	Geomorphological parameters of Tilaiya reservoir catchment	116
7.2	Variation of water storage in Tilaiya reservoir	119

7.3	Variation of sediment load in Tilaiya reservoir	120
7.4	Sediment deposition in Tilaiya reservoir	121
7.4.1	Flow parameters	125
7.4.2	Sediments properties	129
7.4.3	Initial suspended sediment concentrations	133
7.5	Model Simulations for Tilaiya reservoir	133
7.5.1	Eddy Diffusivity and Kinematic viscosity	135
7.5.2	Critical Shear Stress	135
7.5.3	Settling velocities of sediment particles	136
7.5.4	Sediment deposition	137
7.6	Investigating turbidity currents existence	139

Chapter-8 RESULTS AND DISCUSSION FOR TENUGHAT RESERVOIR

8.1	Geomorphological parameters of Tenughat reservoir catchment	148
8.2	Variation of water storage in Tenughat reservoir	149
8.3	Variation of sediment load in Tenughat reservoir	151
8.4	Sediment deposition in Tenughat reservoir	152
8.4.1	Flow parameters	153
8.4.2	Sediments properties	153
8.4.3	Initial suspended sediment concentrations	156
8.5	Model Simulations for Tenughat reservoir	156

8.5.1	Eddy Diffusivity and Kinematic viscosity	159
8.5.2	Critical Shear Stress	159
8.5.3	Settling velocities of sediment particles	159
8.5.4	Sediment deposition	160
8.6	Investigating turbidity currents existence	163
Chapter-9	SUMMARY AND CONCLUSIONS	172
	REFERENCES	180
	APPENDICES	
Appendix I	Main model and sediment model program in C++	190
Appendix II	Input data files	258
Appendix III	Typical output data files	269
Appendix IV	Tilaiya reservoir inflow and outflow data	273
Appendix V	Mean monthly rainfall data for the Tilaiya reservoir catchment for the period from 1987 to 1996	282
Appendix VI	Water levels in Tilaiya reservoir during hydrographic survey 1997	284
Appendix VII	Water levels in Tenughat reservoir during hydrographic survey 2001	285
Appendix VIII	Reservoir level at Tenughat Dam on the last day of the month	286

Appendix IX	Laboratory test results of sediment samples from Tilaiya reservoir	287
Appendix X	Laboratory test results of sediment samples from Tenughat reservoir	288
Appendix XI	Water balance computations for Tilaiya reservoir	289
Appendix XII	Density of sediment water mixture in Tilaiya reservoir	296
Appendix A	Bio-data of Author	297
Appendix B	List of publications from the Present Study	299