THE UNIVERSITY
OF ADELAIDE
AUSTRALIA

Equilibrium Morphological Modelling in Coastal and River Environments: The Development and Application of Self-Organisation- and Entropy-Based Techniques.

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Submitted in fulfilment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

December 2005

FACULTY OF ENGINEERING, COMPUTER AND MATHEMATICAL SCIENCES
School of Civil and Environmental Engineering

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Submitted for examination: DECEMBER 2005
Comments received: MARCH 2006
Ammendments completed: JUNE 2006

Thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

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Abstract

The planning and management of coastal and river structures such as breakwaters, groynes, jetties, bridges and tidal inlets require accurate predictions of equilibrium morphologies. Generally these types of situations are modelled numerically using process-based models, where wave, current and sediment transport modules are applied over a number of time-steps until a steady-state morphology is obtained. Two alternative methods have been developed and applied in this thesis, based on self-organisation and entropy approaches.

The self-organisation-based method utilises a cellular automata model, where local rules produce a global stable pattern through positive and negative feedback. The entropy-based method is able to predict equilibrium morphologies directly. It compares different randomly generated morphologies using an objective function and optimisation, instead of moving to an equilibrium morphology through intermediate states. This avoids some potential problems associated with traditional models such as error propagation and reliance on accurate initial conditions.

The models developed in this thesis have been applied to a number of case studies. It was found that the cellular automata model obtained a higher Brier Skill Score than a comparable process-based model when predicting the equilibrium morphology associated with a channel obstruction. The entropy-based method was able to predict a realistic erosional channel in a coastal lagoon, similar to field observations at the Murray River Mouth in South Australia. It had difficulties predicting the deposition pattern due to the bias of the objective function towards erosional environments. The entropy-based method outperformed a conventional model prediction of the equilibrium erosional channel associated with a laboratory-sized lagoon, but similar problems were observed with its deposition predictive ability.

The modelling methods developed in this thesis are a first step into the use of non-traditional, entropy- and self-organisation-based models for the prediction of complex equilibrium morphologies. They have made use of non-conventional models in order to explore different objective function formulations or self-organisation rules and the sensitivity of these, and have compared the models to laboratory results. The work documented in this dissertation shows that it is possible to use self-organisation- and entropy-based modelling methods to predict stable, equilibrium morphologies in coastal and river environments.

Statement of Originality

I Joanna M. Nield hereby declare that this work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution. To the best of my knowledge and belief, it contains no material previously published or written by any other person, except where due reference is made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available in all forms of media, now or hereafter known.

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Acknowledgements

I wish to thank the many people that have helped contribute to the production of this thesis through their help, advise, support and useful discussions:

- My supervisors Dr David Walker and Assoc. Prof. Martin Lambert, without whom this project would never have made it to the form it is now in. Their ideas, discussions and suggestions have been invaluable.
- My family (Melanie, Steven and Abigail Nield) and Steven Whichelo for all their support over the last 3.75 years. I greatly appreciate their help and perseverance. I also acknowledge the proofreading they have attempted of the Introduction and Conclusion chapters of this thesis, as well as reading my journal and conference papers and listening to practise presentations.
- The role of the Australian Research Council in providing funding for this project and the Department of Water, Land and Biodiversity Conservation as the industry partner (project no. LP0227320).
- Joe Davis for his help in the use of the laser scanner, for being a Matlab guru and never getting sick of me knocking on his door to ask a question.
- The instrumentation and laboratory staff of the School of Civil and Environmental Engineering at the University of Adelaide, for their assistance in the laboratory studies.
- Marcos Bernardes from the University of Plymouth for his help with the Brier Skill Score.
- Researchers at the University of Plymouth and Universitat Politécnica de Catalunya for useful meetings and discussions.
- The organisers, lecturers and participants at the Renesse course, for giving me a strong base, endless list of contacts and many fond memories.
- Everyone that I have met on conferences that have helped me form ideas during lively discussions.

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List of Symbols

Symbol	**Quantity**	**SI Unit**
a	Elasticity of acceptance	-
$A_{ij}(c)$	Metropolis criterion	-
B	Initial or baseline laboratory measurement	m
c	Current temperature	-
c_o	Initial fitness	m^3s^{-1}
d	Mean depth of water	m
D	Local water depth	m
D_{35}	35th percentile of sediment size	m
d_{50}	50th percentile of sediment size	m
d_{90}	90th percentile of sediment size	m
E_e	Average specific energy	m
E_s	Global specific energy contribution	m
f	Objective function value	m^3s^{-1}
f_w	Wave friction factor	-
g	Acceleration due to gravity	ms^{-2}
H	Height of the landscape	m
h	Water depth	m
k_s	Roughness length of the bed	
LL	Lower limit of each decision variable	m
M	Mass	kg
MSE	Mean squared error	m
η	Surface elevation with respect to a datum	m
OF	Overall objective function value	m^3s^{-1}
P_a	Excess steepness penalty	m
P_d	Excess velocity sediment depositing penalty	ms^{-1}
P_e	Excess velocity sediment eroding penalty	ms^{-1}
ρ_s	Density of sediment	kgm^3
ρ	Fluid density	kgm^3
Q	Thermal or heat energy	J
q_{ij}	Sediment transport	m^3s^{-1}
q_t	Volumetric total sediment transport rate	m^2s^{-1}
Q_s	Volumetric transport rate of sediment	m^3s^{-1}
RND	Random number between 0 and 1.	-

Symbol	**Quantity**	**SI Unit**
S	Entropy	JK^{-1}
$SS1$	Random or a predetermined step size	-
T	Period of oscillation	s
T	Temperature	K
t_1	Starting temperature	-
t	Time	s
$\hat{\tau}_0$	Amplitude of τ_0	Pa
τ_0	Shear stress on the bed	Pa
u	Velocity vector component in the x direction	ms^{-1}
UL	Upper limit of each decision variable	m
U_∞	Amplitude of u_0	ms^{-1}
$\overline{U}$	Mean value of u over a vertical	ms^{-1}
$\bar{u}_*$	Time-mean value of u_*	ms^{-1}
$\bar{u}_{cr}$	Critical mean flow velocity	ms^{-1}
ν	Kinematic viscosity	m^2s^{-1}
v	Velocity vector component in the y direction	ms^{-1}
var	Variance in elevation	m
X	Laboratory measurement	m
x	Streamwise distance	m
Y	Numerical model prediction	m
z_0	Baseline elevation	m
z_{crit}	Angle of repose elevation	m
z_{ij}	Predicted elevation	m
λ_p	Bed porosity	-
θ	Scaling factor	-
ψ	Scalar factor	-

List of Abbreviations

ADV	Acoustic Doppler Velocity Meter
BGA	Binary genetic algorithm
BSS	Brier Skill Score
2DH	Two- dimensional, depth averaged horizontal
DHI	Danish Hydraulic Institute
GA	Genetic algorithm
Q3D	Quasi-three-dimensional
RGA	Real genetic algorithm
RMAE	Relative mean absolute error
SA	Simulated annealing
STC	Service Techique Central des Ports Matitimes et des Voies Navigables