Asia-Pacific Network for Global Change Research

Climate Perturbation and Coastal Zone Systems in Asia Pacific Region: Holistic Approaches and Tools for Vulnerability Assessment and Sustainable Management Strategy

Final report for APN project: ARCP2008-07CMY-Dutta

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Project Reference Number: ARCP2008-07CMY-Dutta

Final Report submitted to APN

Overview of project work and outcomes

Non-technical summary

The project has aimed to develop an innovative integrated tool to develop a comprehensive understanding of consequences of climate perturbations and anthropogenic changes in coastal zone systems in the Asia Pacific Region and for examining long-term adaptation and mitigation measures for sustainable management. The focus is on flooding, nutrients, salinity and sedimentation in coastal locations in six countries namely: Australia, Bangladesh, Japan, Sri Lanka, Thailand and Vietnam. The integrated tool comprises three major components: a process model, an impact assessment tool and a multi-criteria decision making tool. The process model, which includes hydrological and biogeochemical processes and their exchange through water and soil and pathways in the river catchment and coastal sea interactions, is designed to generate understanding of changes in these processes due to combined effects of global climate change and anthropogenic developments. The impact analysis tool consists of a series of impact response functions that were developed to assess the impacts of changes in hydro-biogeochemical processes in coastal zone systems. The MCDM tool focuses on factors affecting the sustainability and devising a management strategy for improvement relevant to both government and private policy makers and the community at large. Six coastal areas were selected from the six project member countries in the Asia Pacific region for case study applications of the various components of the integrated tool.

Objectives

The main objectives of the Project was to develop an innovative integrated tool for accurately capturing changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing, for identifying sound metrics for assessment of impacts of these changes and for examining long-term adaptation and mitigation measures for sustainable management. The integrated tool was designed to:

- to accurately capture the changes of hydro-biogeochemcial processes in coastal zone systems in the context of climate change and anthropogenic forcing in the Asia Pacific region,
- to identify sound metrics for assessment of impacts of these changes using TBL concepts, and
- to examine long-term adaptation and mitigation measures for sustainable management.

Amount received and number years supported

Project Duration: 2 years
Funding received from APN in Year1: US$40,000.00
Funding received from APN in Year 2: US$40,000.00

Activity undertaken

The project was implemented in five phases: 1) Planning, 2) Data and Information Collation, 3) Development of Integrated Assessment Tool, 4) Scenario analysis, 5) Final project report, awareness campaign and capacity building. The major activities undertaken in these phases were:

- PRG meetings: several meetings in each of the project member countries.
- Planning Workshop, 27-28 September 2007, Bangkok, Thailand
- Data collection and collation, GIS & temporal database
- Development of Assessment methodology
- Brainstorming Workshop, 16-17 June 2008, Hanoi, Vietnam
- Prototype development
  Case study applications
- International Symposium on Coastal Zones and Climate Change: Assessing the Impact and Developing Adaptation Strategies, 11 – 13 April, 2010, Monash University, Victoria, Australia

Results

The major outputs from the project were:

- A holistic tool to apply LCA and TBL principles to the coastal zone systems in cross-cutting issues for sustainable management of coastal zones.
- Proceedings of the Planning Workshop of the APN Project ARCP2007-14NMY, 27-28 September 2007, Bangkok, Thailand (Appendix B).
- Proceedings of the International Symposium on Coastal Zones and Climate Change: Assessing the Impact and Developing Adaptation Strategies, 11 – 13 April, 2010, Monash University, Victoria, Australia (Appendix C).
- An integrated tool for to develop a comprehensive understanding of the causes and consequences of climate perturbations and anthropogenic changes in coastal zone systems in the Asia Pacific Region and for examining long-term adaptation and mitigation measures for sustainable management.
- Presentations in international conferences/symposia.
- The principal investigator and the collaborators of the project presented the outcomes of the project in several international and national conferences and symposia.
- Published in conference proceedings and journals
- Several peer-reviewed journals and international conference proceedings.
- Final project report.

Relevance to APN's Science Agenda and objectives

The project was highly relevance to the APN Science and Policy Agendas. It has addressed cross-cutting issues covering two main focus areas of the APN Science Agenda. The innovative tool developed in the project by integrating existing and new scientific knowledge on hydro-biogeochemical process modelling, triple bottom line (TBL) analysis, multi-criteria decision making and fuzzy preference modelling is designed to help decision makers to apply Life Cycle Analysis and TBL principles to develop pathways and potential coping mechanisms for sustainable management of coastal zone systems in the Asia Pacific region. The project consisted of a multi-disciplinary team of researchers with expertise in the focus areas of the project from six member countries of South, South-east and East Asia and Pacific (Australia, Bangladesh, Japan, Sri Lanka, Thailand and Vietnam). During the project period, the multi-disciplinary project team has had constant interactions with stakeholders including policy-makers through a project reference group established in each country. The proceedings of the workshops/symposia organized under this project and the outcomes of the case study applications were disseminated to various stakeholders including the members of the project reference groups and other relevant organizations in the member countries. Through this process, the integrated methods and knowledge developed were transferred to decision-making and scientific communities in the member countries.

Self evaluation

The project was highly successful in developing an innovative integrated tool to examine consequences of climate perturbations and anthropogenic changes in coastal zone systems and several case study applications in six countries in the Asia Pacific Region. The outcomes have been presented in several international conferences. Several peer-reviewed papers were published from the project outputs in international journals and conference proceedings (refer to the list of publications).

A highly successful international symposium was held in Australia to present the outcomes of the project. The symposium, explored the potential impact climate change may have on the world's coastal zones, and considered how individuals, communities and governments needed to respond. It has generated large media interests in Australia. Symposium participants heard from 34 speakers (with 22 of these coming from outside Australia) on how climate change and sea level rise was affecting other coastal zones across the country and around the world.

The project has strengthened cooperation between the organizations involved in the project with several other organizations.

These are some of the highly significant outcomes from this successful project.

Potential for further work

- Due to the limited financial support obtained from APN, a large amount of in-kind resources were utilised from the host and collaborative organizations in the development of the tool and undertaking pilot case study applications in six countries. Some of the case study applications are still in progress and need additional resources to complete those.
- The methodology and tool developed in this project has broad applicability in coastal zones. There is a scope to expand the case studies to other major coastal zones of the Asia-Pacific region.
- One of the potential future scientific research is to expand the methodology to incorporate related issues such as groundwater.
- For wider use of the integrated tool, it is highly important to develop good user-interface and technical and user guides.

Publications

Book:

1. Dutta, D. and W. Wright (ed). (2010). *Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies*, Proceedings of the International Symposium, Organized School of Applied Sciences and Engineering, Monash University, Published by Monash University, ISBN 978-0-7326-4011-8, 474 pages.

Report:

1. Dutta, D. (ed) (2007). *Proceedings of the Planning Workshop of the APN Project on Climate Perturbation and Coastal Zone Systems In Asia Pacific Region, Bangkok*, Thailand, 27-28 September 2007, A Report of the Sponsored Research Project, School of Applied Sciences and Engineering, Monash University, 51 pages.

Peer-reviewed Journal Papers:

1. Alam, J.A. and D. Dutta (2011). Predicting climate change impact on nutrient pollution in waterways: a case study in the upper catchment of the Latrobe River, Australia, *Ecohydrology,* (in review).
2. Alam, J.A. and D. Dutta (2011). Development and application of a nutrient dynamics and transport process model in river basins: a sub-catchment based modelling approach, *Hydrological Processes*, (in review).
3. Bhuiyan, J. And D. Dutta (2011). Assessing impacts of sea level rise on river salinity in the Gorai River network, Bangladesh, *Estuarine, Coastal and Shelf Science* (in review).
4. Kabir, M.A., D. Dutta and S. Hironaka (2011). Evaluation of Transport Capacity Equations using Basin Scale Process-based Sediment Dynamic Modelling Approach, *Hydrological Science Journal* (in review).
5. Bhuiyan, J. And D. Dutta (2011). Analysis of Flood Vulnerability and Assessment of the Impacts in Coastal Zones of Bangladesh due to Potential Sea Level Rise, *Natural Hazards* (in review).
6. Kabir, M.A., D. Dutta, S. Hironaka and A. Peng (2011). Analysis of Bed Load Equations and River Bed Level Variations using Basin-Scale Process-Based Modelling Approach, *Water Resources Management* (IF: 2.201) (in press).
7. Dutta, D., W. Wright and P. Rayment (2011). Synthetic Impact Response Functions for Vulnerability Analysis and Adaptation Measures in Coastal Zones under Changing Climatic conditionsClimate Change Conditions: A Case Study in Gippsland Coastal Region, Australia, *Natural Hazards*, doi: 10.1007/s11069-011-9812-x.
8. Kabir, M.A., D. Dutta and S. Hironaka (2011). Process-based Distributed Modeling Approach for Analysis of Sediment Dynamics in a River Basin, *Journal of Hydrology and Earth System Sciences*, 15(4):1307-1321.

9. Dutta, D. (2011). An Integrated Tool for Assessment of Flood Vulnerability of Coastal Cities to Sea Level Rise and Potential Socio-economic Impacts: A Case Study in Bangkok, Thailand, *Hydrological Science Journal*, 56(5):805-823.

Conference Papers

1. Bhuiyan, M.J. and D. Dutta (2011). Modelling Climate Change Impact on the Salinity Distribution in Coastal Zone: A Case Study in Coastal Zone Bangladesh, *Proceedings of the 34th IAHR Congress 2011,* 26 June-1 July 2011, Brisbane, Australia, 3191-3198.
2. Kabir, M.A., D. Dutta and S. Hironaka (2011). Evaluation of Sediment Transport Capacity Equations using Basin-scale Process-Based Modelling Approach, *Proceedings of the 34th IAHR Congress 2011,* 26 June-1 July 2011, Brisbane, Australia, 1403-1410.
3. Bhuiyan, M.J. and D. Dutta (2011). Control of salt water intrusion due to sea level rise in the coastal zone of Bangladesh, *Coastal Processes II, WIT Transaction and the Environment*, WIT Press, 149:163-173.
4. Alam, M.J. and D. Dutta (2010). Grid Based Modelling of Nutrient Dynamics and Transport Process in River Basin: a Case Study - the Latrobe River Basin, Australia, *Proceedings of the 10th International Symposium on Stochastic Hydraulics and the 5th International Conference on Water Resources and Environment Research,* 5-7 July 2010, Quebec City, Canada, 1-7.
5. Alam, M.J. and D. Dutta (2010). Application of a mathematical model for nutrient pollution assessment in a small catchment of the Latrobe River Basin, Australia, *Proceedings of the 6th International Symposium 0n Environmental Hydraulics*, Athens, Greece, 23-25 April 2010, 413-418.
6. Kabir, M.A. and D. Dutta (2010). Analysis of Sediment Dynamics in the Latrobe River Basin, Australia using a Process-Based Distributed Modeling Approach, *Proceedings of the 30th Annual USSD Conference on Collaborative Management of Integrated Watersheds,* 12-16 April, 2010, Sacramento, California, USA, 1285-1296.
7. Wright, W., D. Dutta and P. Rayment (2010). Flood Vulnerability Analysis in Coastal Zones: A Comparative Analysis Across Five Asia-Pacific Countries, *Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies,* 12-13 April, 2010, Monash University, Australia, 433-443.
8. Dutta, D., W. Wright and P. Rayment (2010). Use of Synthetic Impact Response Functions for the analysis of vulnerability to flood damage in Gippsland Coastal Zones, *Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies,* 12-13 April, 2010, Monash University, Australia, 419-432.
9. Alam, M.J. and D. Dutta (2010). Quantification of Climate Change Impact on Nutrient Pollution: Application of a Dynamic Model for Latrobe River Basin in Australia, *Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies,* 12-13 April, 2010, Monash University, Australia, 33-42.
10. Bhuiyan, M.J. and D. Dutta (2010). An Adaptation Strategy for Sea Level Rise Impact on Coastal Cities: A Case Study, South Western Coastal Region of Bangladesh, *Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies,* 12-13 April, 2010, Monash University, Australia, 303-313.
11. Kabir, M.A. and D. Dutta (2010). Analyzing Impacts of Climate Change on Sediment Dynamics in River Basins using a Process-Based Distributed Modeling Approach, *Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies,* 12-13 April, 2010, Monash University, Australia, 19-31.

12. Bhuiyan, M.J. and D. Dutta (2009). Developing Salinity Transport Model to Quantify Climate Change Impact on Coastal Zone in Bangladesh, *22nd Annual Supercomputing Conference, Portland, Oregon, USA*.
13. Kabir, M.A., D. Dutta and S. Hironaka (2009). Process-based Distributed Sediment Dynamic Modelling on a River Basin Scale using High Performance Computing, *22nd Annual Supercomputing Conference, Portland, Oregon, USA*.
14. Alam, M.J., and D. Dutta (2009). Storm Event Based Nutrient Simulation at River Basin Scale, *Proceedings of the 32nd Hydrology and Water Resources Symposium, Newcastle, Australia*, November, 66-77.
15. Bhuiyan, M. and D. Dutta (2009). Sea Level Rise Impacts on Southwest Coastal Region Bangladesh using Hydrodynamic Model, *Proceedings of the 32nd Hydrology and Water Resources Symposium*, Newcastle, Australia, November, 953-964.
16. Kabir, M.A., D. Dutta and S. Hironaka (2009). Analysis of Sediment Dynamics in a River Basin using a Process-based Approach, *Proceedings of the 32nd Hydrology and Water Resources Symposium*, Newcastle, Australia, November, 54-65.
17. Bhuiyan J, Dutta D, 'Analyzing impacts of sea level rise on coastal cities with focus on floods and salinity flux' *USMCA 2009: 8th International symposium on New technologies for Urban Safety of Mega Cities in Asia,* Incheon, Korea, 15-16 Oct, 2009.
18. Alam, M.J., D. Dutta and K. Nakayama (2009). Modelling nutrient dynamics and transport process in river basin: A case study – Saru river, Japan, *Proceedings of the 7th International Symposium on Ecohydraulics*, Concepción, Chile, 12-16 January 2009, pp.1-10.
19. Dutta D, Wright W, Adeloju S (2008). 'A holistic approach for analysing impacts of climate changes on coastal zone systems' *Proceedings of the 7th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia*, pp305-314, China, 21-22 October, 2008.
20. Dutta, D. (2007). Climatic perturbation and flood risk in coastal cities: a comparative study in South and South-East Asia, *Proceedings of the* 6th *International Symposium on New Technologies for Urban Safety of Mega Cities in Asia,* Dhaka, Bangladesh, pp. (6-5-)1-11.
21. Dutta, D., H. Doloi, W. Wright and S. Adeloju (2007). APN Project ARCP2007-14NMY: Background, Objectives, Methodology, Implementation Strategy and Expected Outcomes, *Proceedings of the Planning Workshop of the APN Project on Climate Perturbation and Coastal Zone Systems in Asia Pacific Region, Bangkok*, 27-28 September 2007, Monash University, pp.1-6.

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Technical Report

Preface

Sustainable coastal zone management strategies are imperative in order to avoid extreme social upheaval in both developing and developed countries in the Asia-Pacific region. Significant knowledge gaps prevent the development of such strategies, particularly for developing countries, where much of the population, significant infrastructure and large economic enterprises. The project has aimed to develop an innovative integrated tool to develop a comprehensive understanding of the causes and consequences of climate perturbations and anthropogenic changes in coastal zone systems in the Asia Pacific Region and for examining long-term adaptation and mitigation measures for sustainable management. The focus was on flooding, nutrients, salinity and sedimentation in coastal locations in six countries namely: Australia, Bangladesh, Japan, Sri Lanka, Thailand and Vietnam. A series of case studies were conducted in several selected coastal zones in the six project member countries in the Asia Pacific region using the integrated tool. The project methodology, results of the case study applications and the key findings are presented in this report. The project team is grateful to School of Applied Sciences and Engineering of Monash University for the significant contributions towards the successful completion of the project.

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1. Introduction

The impact of climate change in environment has already been evident across the globe. Since release of the 4^{th} Technical Report AR4 of the Intergovernmental Panel on Climate Change (IPCC) in 2007 scientific understanding has improved remarkably over the last 3-4 years and it appears overwhelmingly that climate system is likely to be changing faster than it was thought before- which means more serious risk (Steffen, 2009).

In recent years, there has been an increasing concern, particularly with the growing population, rapid urbanization and industrial developments in coastal areas of Asia Pacific region that the current management practices adopted in most of these countries are unsustainable (Hong *et al.*, 2002). It has been realized that the rapid developments, extraction or manipulation of resources can not exceed the sustainable limits without compromising the ecological integrity of the coastal ecosystems. This has now led to a growing concern that if the current trend of growth and exploitation continues, it would result in adverse effects on social, economic and environmental well-being in coastal zones. The extents of these consequences are further exacerbated by the adverse impacts being incurred from global climate change including extreme climatic events and sea level rises (IPCC CZMS, 1992; Titus, 1998; IPCC, 2001; Mitchell *et al.*, 2000; Dutta *et al.*, 2005).

Sustainable coastal zone management strategies are imperative in order to avoid extreme social upheaval in both developing and developed countries in the Asia-Pacific region. Significant knowledge gaps prevent the development of such strategies, particularly for developing countries, where much of the population, significant infrastructure and large economic enterprises such as shrimp fisheries are concentrated in the coastal zones. Lives, livelihoods, infrastructure and the environment are at risk from flood events; and information to facilitate effective planning is required.

While there is a little chance to act against rules of nature, strategies for adaptation these changes could be a potential solution. However, in order to devise appropriate solutions for adaptive policies, information uncertainty and conflict management are thus critical issues. Environment related problems are characterised by complexity, uncertainty and irreversibility. Evaluation methods are not always quite straight forward Improvement of one problem dimension cannot compensate for deterioration in another dimension.

To enable a comprehensive understanding of the changes in the physical processes due to the combined effects of climate and human-induced changes, a spatially distributed process-based integrated approach, is essential, which models the different inter-connected processes at appropriate spatio-temporal resolutions (Gordon *et al.*, 1996; Hong *et al.*, 2002; Nakayama *et al.*, 2004). A holistic approach (that combines physical modelling, vulnerability assessment with TBL and LCA principles and MCDM tools) to coastal zone management is needed to resolve the conflicting demands of society for products and services, taking into account both current and future interests (Post & Lundin, 1996; Neumann and Livesay, 2001; Walsh, 2004; APN, 2005; Dutta *et al.*, 2005). Agenda 21 and in particular its Chapter 17 'Protection of The Oceans' reaffirmed this need. Given these scenarios, the real challenge in achieving optimal sustainable management strategy in coastal zones relies on the ability to design, develop and implement an integrated management program that not only maximizes benefit to society and economy based on accurate understanding of the impacts of changes in physical processes, but that also ensures that the ecosystems are adequately protected or preserved.

In response to the need for sustainable management practices, several developed countries have developed and/or implemented sustainable coastal zone management strategies (Thom, 2002; Walsh, 2004). The developing countries in the Asia-Pacific region, still lagging behind in this front, have revealed some knowledge and approach gaps, thus presenting the opportunity to break new ground on subsequent strategies. The strategies should be the vehicle for facilitating

Integrated Coastal Zone Management (ICZM) principles, but how this can be done is still unclear and yet to be demonstrated (Clark, 1992; Post and Lundin, 1996; Wlash, 2004).

The project has aimed to develop an innovative integrated tool for accurately capturing changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing, for identifying sound metrics for assessment of impacts of these changes and for examining long-term adaptation and mitigation measures for sustainable management. Its main objective was to develop a more holistic approach and tool to apply Life Cycle Analysis (LCA) principles to the coastal zone systems in cross-cutting issues in the Asia Pacific region. In doing so, this project intends to overcome the limitations of the existing fragmental approaches for evaluating more complex and interrelated biogeochemical and physical processes in coastal zones that include nutrient flux, salinity, floods, erosion and sedimentation and their impacts on society, economy and environment. To achieve these goals, the project has focused on selected coastal zones which will have all of these attributes in six countries within the Asia Pacific region.

2. Methodology

The project has taken a systematic approach for developing a holistic assessment methodology and prototype and its implementation. The holistic assessment tool comprises three major components as shown in Figure 1.

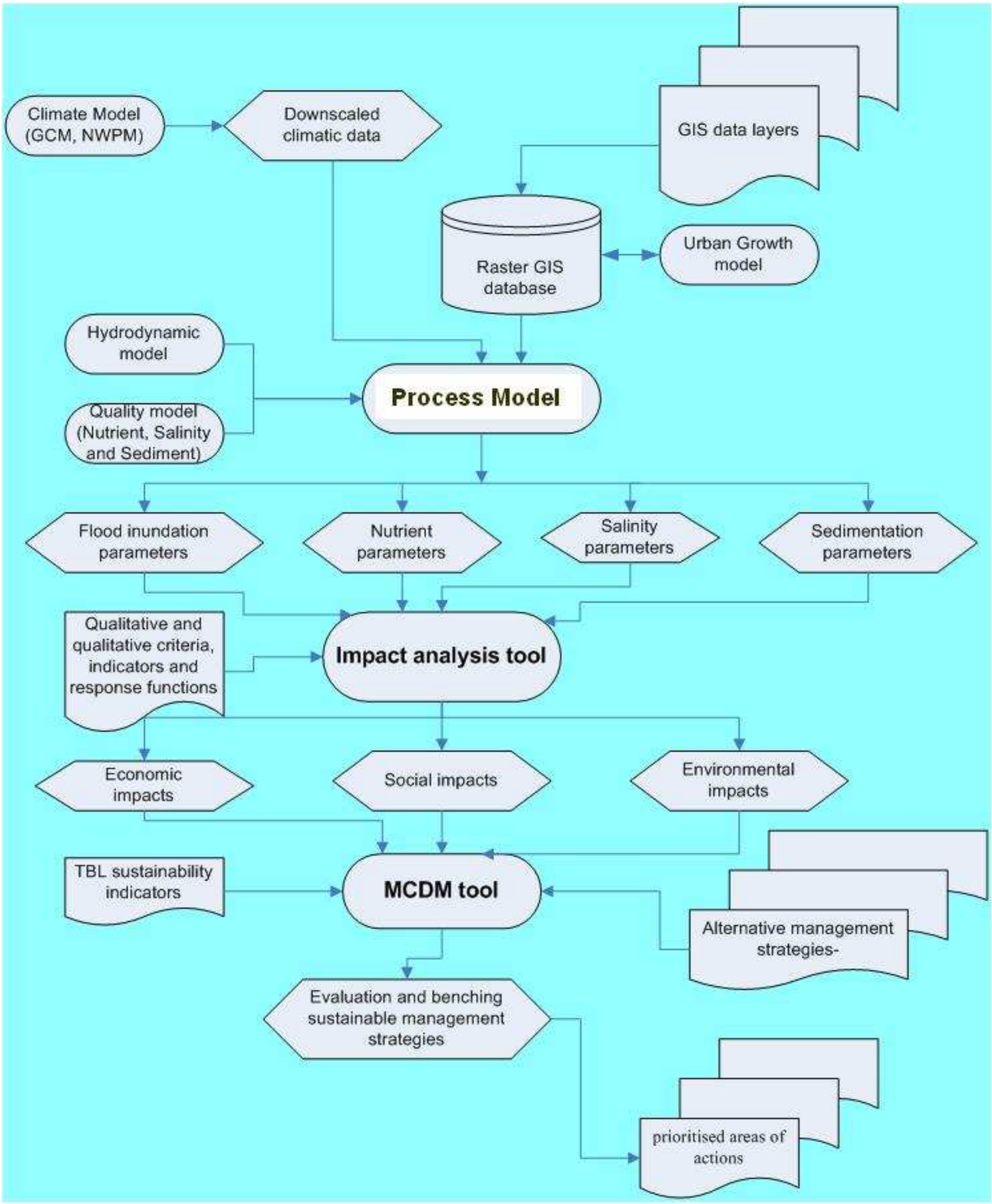


Figure 1: Project Methodology

1) Process model:

An integrated process model was built on existing and new scientific knowledge of different physical processes in coastal zone systems including hydrological and biogeochemical processes and their exchange through water and soil and pathways in the river catchment and coastal sea interactions for scientific understanding of changes in these processes due to combined effects of global climate change and anthropogenic developments (Gordon et al., 1996, Hong et al., 2002; Nakayama et al., 2004; Garnier et al., 2005; Bhattarai and Dutta, 2005; Nakayama, 2005; Dutta et al., 2006).

2) Impact Assessment Tool:

All the social, economic and environmental factors affected by changes in the physical processes are identified and a set of criteria, indicators and appropriate response functions relating to the changes was established. Using these functions and predictive outcomes of modelling of physical processes, detailed quantitative assessment of social, economic and environmental impacts in coastal zones under climate changes and anthropogenic developments were carried out.

3) Multi-Criteria Decision Making tool:
A set of criteria and indicators were developed representing social, economic and environmental sustainability of coastal zone systems. Fuzzy Preference modelling with multi-objective optimisation approach was used to model the stakeholder's preferences and expectations in the decision appraisal process (Doloi and Jaafari, 2002; Manivong et al, 2004). Using these criteria and indicators, a multi-criteria decision making system will be established for strategic planning, policy development and enhancement and pathways for sustainable management of coastal zones.

The theory and conceptualisation of each of these three major components are discussed in the following section.

2.1 Physical Model

The Process Model has three major sub-components:

- Hydrodynamic model
- Salinity Model
- Sediment Transport Model
- Nutrient Dynamics Model

2.1.1 Hydrodynamic model

The hydrodynamic model was originally developed at the Public Work Research Institute (PWRI) of Japan. The model has two components: river flow and overland flow. The model has been widely applied for flood modelling and risk analysis in many Asian river basins (Bhuiyan et al, 2005; Dutta & Bhuiyan, 2007). For simulating surface flow process, the study area is first discretized into square grids. Unsteady equations are derived from continuity and momentum equations for one dimensional as well as two dimensional flows. For river flow component, the finite difference equation for one dimensional channel flow is solved in every grid of the channel for water level and discharge. The model uses explicit solution scheme for river flow calculation. The form of momentum equation is shown below.

$$A\frac{dQ}{dt} + Q^2\frac{d\beta}{dx} - 2\beta Q\frac{dA}{dt} - \frac{\beta Q^2}{A}\frac{dA}{dx} + gA^2\frac{dH}{dx} + \frac{A}{\rho}T_r = 0$$

$$T_r = \rho g A\frac{Q^2}{[\Sigma\frac{A}{n}R^{2/3}]^2}$$

Where, A = river cross-section, Q = river discharge, T_r = river bottom shear, H = water level, R = hydraulic radius.

For overland flow component, fundamental equations of two dimensional unsteady flows are constructed from continuity equation and equation of motion. The continuity equation and he equations of motion in x and y directions are shown below.

Continuity equation:

$$\frac{\partial h}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0$$

Momentum equation in x-direction:

$$\frac{\partial M}{\partial t}+\frac{\partial uM}{\partial x}+\frac{\partial vM}{\partial y}+gh\frac{\partial H}{\partial x}+\frac{1}{\rho}\tau_x(b)=0$$

Momentum equation in y-direction:

$$\frac{\partial N}{\partial t}+\frac{\partial uN}{\partial x}+\frac{\partial vN}{\partial y}+gh\frac{\partial H}{\partial y}+\frac{1}{\rho}\tau_y(b)=0$$

Where, H = water level from datum, h = depth of water, u = flow velocity in x direction, v = flow velocity in y direction, g = gravitational acceleration, ρ = density of water, M = discharge flux in x direction ($M = uh$), N = discharge flux in y direction ($N = vh$), $\tau_x(b)$ = bottom shear stress in x direction, $\tau_y(b)$ = bottom shear stress in y direction.

The main characteristic of the model is the link between unsteady calculation in river channel and calculation of flood in river basin to reproduce the flood inundation phenomenon in large scale over the whole river system. The relation between stages in river channel and height of levee decides the points and scale of flood levee failure with unsteady calculation in river channel.

2.1.2 Salinity Model

A salinity transport model has been developed to investigate transport processes through estimating the advection dispersion coefficients and integrated with the hydrodynamic model. The transport and dispersion of solute in the longitudinal case involves a mathematical representation in the form of the following single dimensional, partial differential equation (Fischer et al., 1979; Orlob, 1983; Henderson-Seller et al., 1990; Young and Wallis, 1992), usually known by Fickian Diffusion Equation or Advection Dispersion Equation (ADE),

$$\frac{\partial C(s,t)}{\partial t}+U\frac{\partial C(s,t)}{\partial s}=D\frac{\partial^2 C(s,t)}{\partial s^2}$$

where, $C(s,t)$ is the concentration of the solute at spatial location s and time t; U is the cross-sectional average longitudinal velocity; and D is the longitudinal dispersion coefficient.

The distance-time (x-t) planes for formulating explicit finite difference schemes of advection dispersion equation is shown in Figure 2.

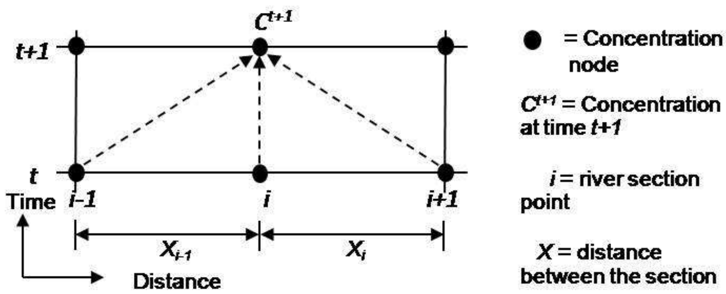


Figure 2: Distance-time plane in the solution scheme of salinity model

2.1.3 Sediment Dynamics Model

The sediment dynamic model is an integration of a process-based distributed hydrological model with sediment modules. The adopted distributed hydrological model (DHM) is developed at the University of Tokyo (Dutta *et al.* 2000), which considers the watershed as an array of homogeneous grid cells to capture the catchment spatial heterogeneity. The model represents all the components of hydrologic cycle mathematically based on their physical governing equations and then simulates the movement of water from cell to cell using the principles of conservation of mass and momentum. All the hydrologic components of this model can be described as five distinct modules: (i) Interception and evapotranspiration simulation module, (ii) Unsaturated zone flow simulation module, (iii) Saturated zone flow simulation module, (iv) Overland flow simulation module and (v) Channel network flow simulation module.

The sediment modules represent sediment processes such as, soil erosion, sediment transport and deposition, with the driving hydrological components. The modules are categorized as rainfall impact detachment simulation module and flow detachment or deposition simulation modules. The rainfall impact detachment simulation module estimates total eroded soil using the relationship between kinetic energy and the amount of detached soils, proposed by Torri *et al.* (1987). The module for soil detachment and deposition has been followed the equations as described on Morgan *et al.* (1998), which is based on generalized erosion-deposition theory proposed by Smith *et al.* (1995). Govers (1990) transport capacity equation has been used to estimate transport capacity concentration (*TC*) due to its simple structure and easily available input dataset. The flow detachment simulation module is considered soil cohesion since cohesion force encounters detachment processes in case of cohesive soil. Table 1 summarizes all the governing equations used in different sediment modules as described in this section.

The sediment modules are linked as sub-components within the distributed hydrological model under the FORTRAN programming environment. The overall sediment dynamic model indicating different modules with their simulation sequence is shown in Figure 3. A one-dimensional kinematic wave approximation of the Saint-Venant equations for continuity and momentum is conveniently applied in this model application to simulate surface and river flow movement based on the direction of steepest descent. This is because, in Latrobe River basin, the flow is mostly unidirectional and back water effect is insignificant. Thus, it has efficiently been chosen to reduce computational time considerably and to make suitable for large scale river basin simulation incorporating sediment dynamic modules with driving hydrological components.

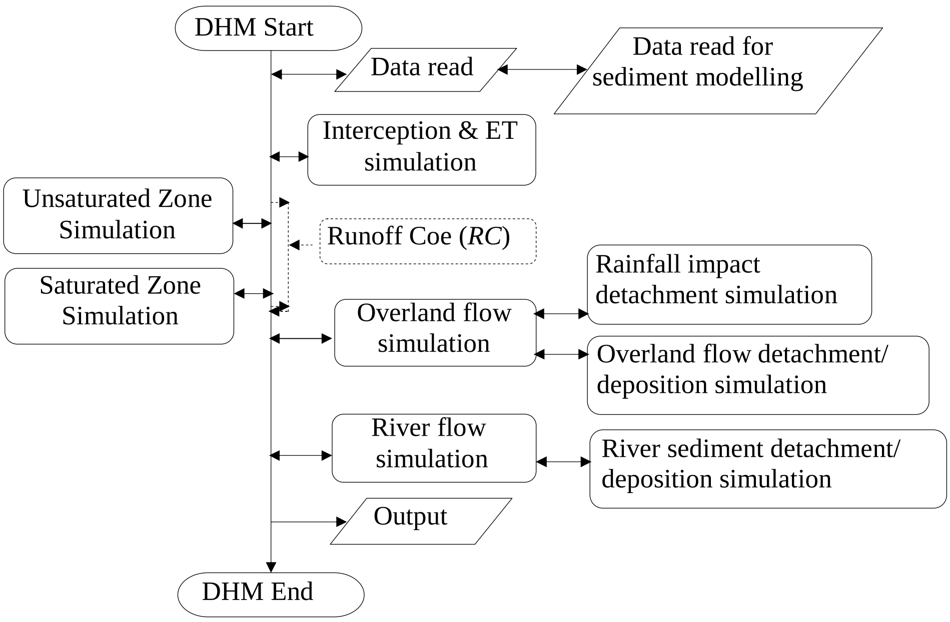


Figure 3: Structure of process-based sediment dynamic model

Table 1: Governing equations used in sediment modules

Modules	Descriptions
Rainfall impact detachment simulation	Soil detachment (Torri *et al.* 1987), $D_R = \frac{k}{\rho_s}(KE)e^{-ZH}$ k is the soil detachability index, ρ_s is the soil density, e^{-ZH} is the correction factor for water ponding, where Z depends on soil texture, H is surface water depth. KE is the kinetic energy, For direct rainfall impact (Brandt, 1989), $KE(DT) = 8.95 + 8.44\log(I)$ For leaf drip impact (Brandt, 1990), $KE(LD) = 15.8(PH)^{0.5} - 5.87$ I is the rainfall intensity, PH is the canopy height
Flow detachment/ deposition simulation	Flow detachment or deposition (Morgan *et al.* 1998), (Positive sign for detachment and negative for deposition) $D_F = \beta w v_s (TC - C)$ C is sediment concentration, w is the width of the flow, v_s is the particle settling velocity, β is a correction factor in case of cohesive soil erosion. TC is the transport capacity concentration (Govers, 1990), $TC = c(\omega - \omega_{cr})^{\eta}$ Where, $\omega = 10\,u\,s$, $c = [(d_{50} + 5)/0.32]^{-0.6}$, $\eta = [(d_{50} + 5)/300]^{0.25}$ ω is the unit stream power, u is the mean flow velocity, s is the slope in percentage, ω_{cr} is the critical value of unit stream power, c and η are coefficients depending on median particle size, d_{50} of the soil. The transport capacity equation is suitable for particle size ranging from 50 to 250 μm with sediment concentrations maximum up to 0.32 m^3m^{-3}.

2.1.4 Nutrient Dynamics Model

The modelling approach consists of three components as shown in Figure 4. Catchment generation process has been dealt with for accounting soil nutrient transformation process. The transfer mechanism of nutrients from surface to the waterways has been considered via pathways for soil erosion and surface runoff. The river component deals with dynamic transport and biogeochemical process in river water. The model has been developed in an existing platform of distributed hydrological modelling tool called IISDHM (Dutta et al., 2000).

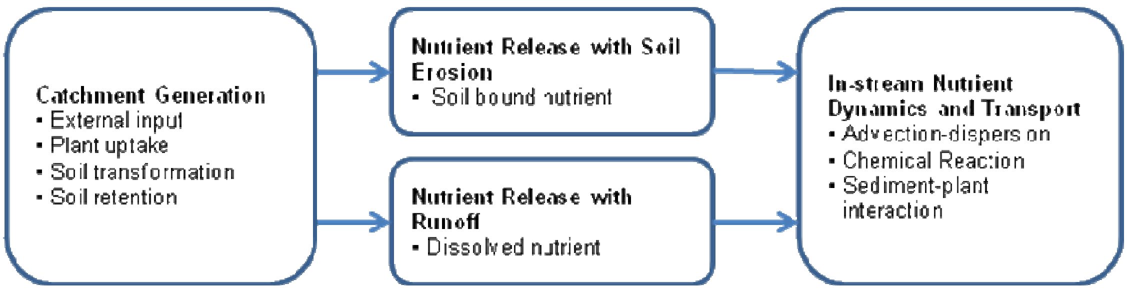


Figure 4: Integrated modelling approach

Catchment generation process

Sub-catchment based approach has been adopted for catchment process modelling. The model takes into account of transformations process of organic nitrogen and phosphorus in soil layer. Mineralization and immobilization has been considered to calculate net generation of ammonium *N* and phosphate *P*. Nitrification and de-nitrification determine the nitrate level and losses of nitrogen through atmosphere. Nutrient consumption for plant growth is determined based on uptake equation (Whitehead et al., 1998 a, b). The reaction processes depends on the soil moisture condition and temperature in soil layer. These equations are shown in Tables 2 and 3.

Table 2: Equations for nitrogen transformation process in soil layer (Whitehead et al., 1998 a,b)

Process	**Equations**
Plant Uptake	$Uptake = C_{up}u_i\left(x_{NO_3} + x_{NH_4}\right)$ Where, C_{up}= plant uptake rate (day^{-1}), X_{NO3} = amount of nitrate, X_{NH4} = amount of nitrate,
Mineralization-immobilization	$Net\ Mineralization = C_{mina}S_i - C_{imm}X_{amm}$ Where, C_{mina}= Mineralization rate (g day^{-1}), *SMI*=soil moisture index, C_{imm}= Immobilization rate (day^{-1}), X_{amm}= Ammonium *N* content
Nitrification	$Nitrification = C_{nitri}U_w X_{NH_4-N}$ Where, C_{nitri}= Nitrification rate (day^{-1}), X_{NH_4-N} = Ammonium *N* content
Denitrification	$Denitrifca\ tion = C_{deni}U_w X_{NO_3-N}$ Where, C_{deni}= Denitrification rate (day^{-1}) , X_{NO_3-N} = Nitrate N content
Temperature correction	$C_n = 1.047^{(\theta_s - 20)}C$ Where, C_n =rate coefficients (day^{-1}), *C*= rate coefficients (day^{-1}) at 20°C, θs= Soil temperature

Table 3: Equations for phosphorus transformation process in soil layer

Process	**Equations**
Plant Uptake	$Uptake = C_{up}u_i x_{PO_4}$ Where, C_{up}= uptake rate (day^{-1}), u_i= plant growth index, x_{PO_4} = amount of Phosphate P
Mineralization-immobilization	$Net\ Mineralization = C_{mina}S_i - C_{imm}X_{DPO_4}$ Where, C_{mina}= Mineralization rate (g day^{-1}), *SMI*=soil moisture index, C_{imm}= Immobilization rate (day^{-1}), X_{DPO_4} = amount of dissolved *PO4*.

The soil moisture index (SMI) has been determined based on the soil moisture deficit (SMD) in the soil layer. The index is zero when maximum moisture deficit and 1 in saturation. The *SMI* and *SMD* can be calculated as below.

$$SMI = \frac{SMD_{Max} - SMD}{SMD_{Max}}$$ (Whitehead et al. 1998a,b)

$$\frac{dSMD}{dt} = -P_{eff} + ET$$ (Finkele et al. 2006)

Where, P_{eff} (rain-interception-runoff) = effective rainfall and *ET*= Evapo-transpiration.

Ensuring mass balance of the different transformation process the release of nutrient has been estimated based on the following equations.

$$(NH_3 - N)_t = Ext_{input} + mineralization - immobilization - uptake$$
$$(NH_3 - N)_{release} = (NH_3 - N)_t * U_w$$
$$(NO_3 - N)_t = Ext_{input} + nitrificat\ ion - uptake - denitrific\ ation$$
$$(NO_3 - N)_{release} = (NO_3 - N)_t * U_w$$
$$(DPO_4 - P)_t = Ext_{input} + mineralization - immobilization - uptake$$
$$(DPO_4 - P)_{release} = (DPO_4 - P)_t * U_w$$

Where, suffix t denotes computational time level; NH_4-N, NO_3-N and DPO_4-P are ammonium, nitrate and dissolved phosphate, respectively; Ext_{input}= all input associated with external sources on the surface, mineralization is net load of mineralized ammonium N and phosphate P, immobilization denotes amount immobilized, denitrification is loss of nitrate, *uptake* = consumption for plant growth. A pollutant load function U_W has been introduced to account of storm and land surface type when determining dissolved nutrient release with runoff.

$$U_W = aQ^b$$

Where, a = coefficient for soil and land cover effects, b= power factor, Q = Flow (m^3/s).

Sediment yield and estimation of organic or soil bound nutrients
MUSLE (Williams 1975; Williams & Berndt, 1977) has been used to generate sediment yield. Based on the sediment yield soil bound or organic nutrient has been calculated as below (Leon et al., 2001).

$$N_{SED} = N_{SCN} Y_{SED} ER$$
$$P_{SED} = P_{SCN} Y_{SED} ER$$
$$E_R = a Y_{SED}^b T_f$$

Where N_{SED} = nitrogen transported by sediment (kg ha^{-1}), N_{SCN}= soil nitrogen concentration. Similarly, P_{SED} = phosphorous transported by sediment (kg ha^{-1}), P_{SCN}= soil phosphorous concentration. Y_{SED} = Sediment yield, ER = Nutrient enrichment ratio, a and b are enrichment coefficients, T_f = correction factor for soil texture.

In-stream process and river transport modelling
Using explicit solution scheme in finite difference method Advection-dispersion equation has been solved to calculate nutrient concentration at each river grid. First order reaction has been considered in this equation for all chemical reaction and in-stream biogeochemical process (Chapra, 1997).

$$V \frac{\partial c}{\partial t} = \underbrace{\frac{\partial \left(A_c E \frac{\partial c}{\partial x} \right)}{\partial x} dx - \frac{\partial (A_c U c)}{\partial x} dx}_{Advection - dispersion} + \underbrace{V (rc + p)}_{Reaction} + \underbrace{S}_{sorce/sink}$$

Where, V = element volume, c= nutrient concentration, A_c= element cross-section area, E= Longitudinal dispersion coefficient, X= space unit, t= time, U= average velocity, r=reaction rate, p= internal source/sink through transformation, s= external loading (source/sinks).

2.2 Impact Analysis Tool

The impact analysis tool consists of a series of impact response functions that were developed to assess the impacts of changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing. Impact response functions are essential components of vulnerability and impact assessment models, which relate impacts of flood inundation and water quality variables to key issues (Krzysztofowicz and Davis, 1983; Smith, 1994). There are several types of hazards for coastal areas associated with climate change and sea level rise. In this study, the hazard of interest is flooding. The flood inundation variables which govern the impact characteristics and which are considered for stage-damage functions are: flood depth, duration, velocity and frequency and water quality. The response functions are usually derived in one of two ways. Damage data from past floods may be incorporated into the model, but if such information is unavailable or unreliable, an alternative approach is to generate synthetic response functions from hypothetical analyses of flood events based on land cover and land use patterns and the key issues for the region (Das and Lee, 1988; Smith and Greenaway, 1988; Smith, 1994). Berning *et al.* (2001) call for incorporation of social and environmental components into these models, but damage functions for these elements of a model are difficult to estimate (Dougherty & Hall, 1995; Kang *et al.*, 2005). According to Viljoen *et al.* (2001), including the environmental impact dimension into the holistic damage assessment methodology should render further benefit. Various authors including Dougherty & Hall (1995) suggest use of expert advice in determining synthetic response/loss functions. In this study, information regarding the likely impact of inundation on key issues with social, economic or environmental values was generated by surveying stakeholders with experience of past flood events.

The vulnerability analysis required the identification of relevant flood hazard parameters and key issues for the study region; and the synthesis of impact response functions using expert and stakeholder opinion. The outcomes of the vulnerability analysis are potentially useful as a basis for the development of adaptation measures for the region. The project required the engagement of experts and key stakeholders in order to identify and prioritize the key issues and to generate synthetic response functions. The approach used for the development of response functions included five major steps:

- Identification of hazard parameters and key issues
- Questionnaire design
- Administration of the Questionnaire
- Statistical Analysis of the questionnaires
- Sensitivity Analysis

A systematic approach was taken throughout the development of the impact response functions, from the selection of experts and stakeholders to the design and distribution of the questionnaires and to the statistical analyses of the data provided by stakeholders, which in turn enabled the prioritization of issues and impact response functions for adaptation measures. The roles of the experts and stakeholders were to identify relevant flood hazard parameters and key issues for the region; and to provide data for the generation of synthetic response functions for impact analysis. The questionnaire was devised as an instrument to collect data for generating synthetic response functions. Each aspect of the project activities and approach is discussed below.

Identification of hazard parameters and key issues

Two groups were formed in order to identify relevant flood hazard parameters and key issues for the study region. A 'Stakeholder Reference Group' was formed by inviting stakeholders from government, non-governmental and industry sectors familiar with the region and its natural resource management issues. The main criteria used for selection of stakeholders were: interest in the topic, familiarity with regionally relevant issues and appropriate educational qualifications and/or work experience in relevant projects. The second group was formed by recruiting international water and coastal zone experts from six countries of the Asia-Pacific region. Members of this expert group had been working collaboratively on a project on coastal zones and climate change (Dutta, 2007).

Each of the two groups was engaged in brainstorming meetings in order to identify the most important flood inundation and water quality parameters (hazard parameters) associated with coastal zone flooding that could be simulated by the process-based model. In addition, the groups identified the key social, economic and environmental issues on which these hazard parameters could impact. The key issues were used to develop a set of criteria, indicators and appropriate response functions relating to various scenarios where the intensity of the flood hazard parameters varied due to climatic and anthropogenic changes in the study area. (Belfiore, 2003). Tables 4 and 5 show the flood inundation parameters (4), water quality parameters (3), and the key issues (22) identified for impact analysis, respectively.

Table 4: Flood inundation & water quality parameters to be modelled under climatic change conditions

Flood inundation parameters	**Water quality parameters**
Depth, Duration, Velocity, Frequency	Nutrients (TN, NO_2, NO_3, TP, PO_4), Salinity, Turbidity

Table 5: Key issues in coastal areas identified for climate change impact analysis

Key issues (with abbreviations)	
Infrastructure	*Drainage (Dr)*
	Roads (Rd)
	Railways (Rl)
	Ports & Harbours (Pt)
	Dykes (Dy)
	Coastal protection structure (Co)
	Landuse planning (LU)
Buildings	*Residential (RB)*
	Non-residential (NR)
Potable water (PW)	
Water quality (WQ)	
Erosion (Er)	
Tourism (To)	
Population	*Short-term displacement (SD)*
	Long-term resettlement (LD)
Agriculture (Ag)	
Fishery (Fi)	
Fish habitat/distribution (FH)	
Wetland health	*Extent (WEx)*
	Flora biodiversity - no. of veg. species (WFl)
	Fauna biodiversity - no. of bird species)(WFa)
Mangroves (Ma)	

Questionnaire design

A questionnaire was designed to gather information regarding stakeholders' views of the likely impacts of various levels of coastal inundation on key issues and assets in the study area. For the purpose of structuring the questionnaire, magnitudes of different flood inundation and water quality parameters were classified into three categories: low, medium and high. The stakeholder and expert groups were both consulted regarding the suitability of these categories, and a range of references were used to finalize realistic magnitude ranges for the flood inundation and water quality parameters within these three categories for coastal lakes and wetlands in the study areas. These take account of generally accepted standards for aquaculture, wetland biodiversity, recreational activities, etc. Tables 6 & 7 show the magnitude ranges of different flood inundation and water quality parameters for the three categories for Australia.

Table 6: Flood inundation magnitude scale

Category	**Depth (m)**	**Duration (days)**	**Velocity (m/sec)**	**Frequency (return period)**
Low	<0.6	< 0.5	< 0.5	> 20 yrs

Medium	0.6-1.5	0.5-2	0.5 – 1	5-20 yrs
High	>1.5	>2	> 1	< 5 years

Table 7: Water quality magnitude scale

Category	**TN (µg/L)**	**NO_2^- (µg/L)**	**NO_3^- (µg/L)**	**TP (µg/L)**	**PO_4^{3-} (µg/L)**	**Salinity (µ S/cm)**	**Turbidity (NTU)**
Low	<350	<10	<10	<10	<5	< 30	< 5
Medium	350-750	10–50	10-50	10-30	5-10	30- 100	5-20
High	>750	>50	> 50	>30	>10	> 100	> 20

(*TN = Total nitrogen, NO_2=Nitrite, NO_3=Nitrate, TP=Total phosphorous, PO_4= Phosphate, Salinity: measure of concentration of total dissolved solids in water, µg/L: micrograms per litre, mg/L: milligrams per litre, µS/cm: Micro siemens percentimetre, NTU: nephlometric turbidity units)*

The questionnaire was designed by the group of international experts in order to generate data describing stakeholders' assessments of the different impacts of the three categories of flood inundation and water quality parameters (as given in Table 4) on key social, economic and environmental issues (as given in Table 5). The data collected was used in the formation of synthetic response functions relating the level of flooding to the level of impact. The main purposes of the questionnaire were: to investigate which issues (assets) were of most concern to stakeholders; whether the intensity (high, medium or low) of flood parameters affects those issues of most concern; and to facilitate development of synthetic response functions

Administration of the Questionnaire

Stakeholder reference group participants provided anonymous responses to the questionnaire. The questionnaire was lengthy and reasonably complex and required respondents to indicate their perceptions of the likely level of negative impact for each of the flood inundation and water quality parameters on each of the key issues (for each of the three conditions (high, medium, low). Respondents used an impact ranking score in the range 1-5 to indicate predictions regarding the extent of the impact in each case. The instructions within the questionnaire defined each of the ranking scores as per Table 8. The participants were explicitly given the option of not completing those sections of the questionnaire that were perceived as beyond their expertise.

Table 8: Impact ranking scores and their definitions as used in the questionnaire

Impact ranking score	**Impact definition**
1	No/little impact (0-5% damage)
2	Low Impact (5-25% damage)
3	Moderate impact (25-50% damage)
4	High impact (50-75% damage)
5	Extreme impact (75-100% damage)

Statistical Analysis of the questionnaires

A statistical method was designed to analyse the data obtained from the returned questionnaires and to create synthetic response functions. In relating the impact ranking score for a particular flood inundation or water quality parameter, x, on an individual key issue (such as drainage or agriculture), the impact ranking score (1-5 integer scale), y was analyzed, rather than its associated predicted percentage damage (Table 8). This was done in order to homogenize the spreads of response scores across the low, medium and high levels of magnitude of each parameter.

For any combination of parameter and issue, the number, s, of stakeholder survey responses ranged from 21 to 33, since 12 respondents did not complete the section of the questionnaire relating to the water quality parameters. Denoting the low, medium and high responses for the *i*th individual stakeholder by y_{Li}, y_{Mi} and y_{Hi} respectively,

$$b_i = \frac{y_{Hi} - y_{Li}}{2}$$

is the slope of the fitted least squares regression line (assuming equal spacing of the three parameter levels).

In the next step of the statistical analysis, responses of all stakeholders were combined for each hazard parameter. A 95% confidence interval for the underlying slope (CIs) was calculated as shown in the equation below.

$$CI_s = \overline{b} \pm t^* \times se(\overline{b})$$

Here, $\overline{b}$ is the mean value of slope, $se(\overline{b})$ is the standard error of $\overline{b}$ and t* is the 97.5th percentile of the t distribution with (s-1) degrees of freedom.

The half-width of the above confidence interval was used as a numerical indicator (termed 'disparity') of the level of agreement among respondents, as well as assisting in developing an inference for the underlying impact.

The quadratic response function fitting the three points $(L, \overline{y}_L)$, $(M, \overline{y}_M)$ and $(H, \overline{y}_H)$ was determined for each combination of hazard parameter and issue as a basis for comparisons across issues.

Sensitivity Analysis

Relationships between the impact ranking scores for the effects of high, medium and low magnitudes for all combinations of flood hazard parameters and key issues were grouped into the following four classes (Figure 5):

Class 1: High sensitivity & High Agreement (or low disparity)
Class 2: High sensitivity & Low Agreement (or high disparity)
Class 3: Low sensitivity & High Agreement (or low disparity)
Class 4: Low sensitivity & Low Agreement (or high disparity)

The key issues that show high sensitivity to increasing magnitude for a particular hazard parameter (i.e., steep slope or high $\overline{b}$ value in Eq. 1) and for which there is high agreement among respondents (i.e., high correlation or narrow confidence interval for the slope CIs) are placed in Class 1. All the key issues in this class show a reasonably strong, linear relationship with increasing magnitude of the particular flood hazard parameters; and good agreement among stakeholder respondents about these relationships. Key issues in Class 2 appear to be sensitive to the increasing magnitude of the hazard parameters, the opinions of different stakeholders about these relationships are varied. Class 3 includes key issues which stakeholders agree are not particularly affected by an increase in magnitude of the hazard parameters. The key issues in Class 4 also appear to be less sensitive to the hazard parameters, however, there are more widely varying perceptions among stakeholders about these relationships. The criterion used to define sensitive issues was $\overline{b} \geq 0.5$. The criterion used to define high agreement was a disparity measure of below 0.3. A disparity measure above or equal to 0.3 was considered to indicate low agreement.

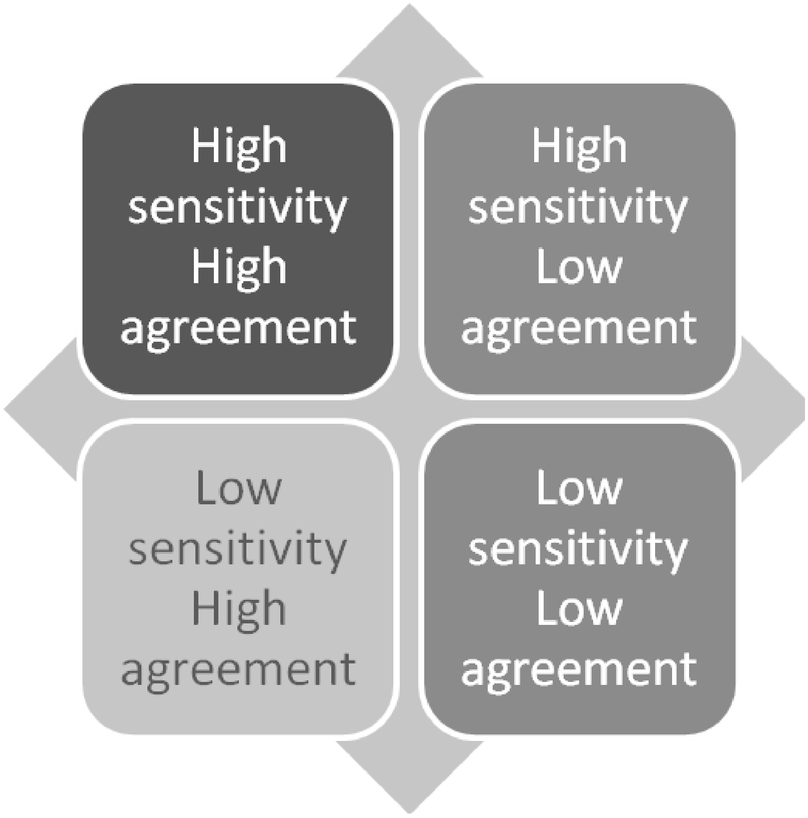


Figure 5: Grouping of relationships between flood hazard parameters and important issues

2.3 MCDM Tool

The MCDM tool focuses on factors affecting the sustainability and devising a management strategy for improvement relevant to both government and private policy makers and the community at large. Selecting the most appropriate alternative from a set of alternatives and eliciting the consistent subjective judgment from the decision makers in the selection process require a holistic analysis. In general, this selection process is more effectively performed with the aid of computerised decision support systems. Some of the past researchers have adopted questionnaire survey approach for data collection in measuring various success and failure attributes and employed mathematical tools such as Analytical Hierarchy Process (AHP) (Saaty, 1980), Artificial Neural Networks (ANN) and statistical techniques such as factor analysis and multivariate regression etc. for analysis and drawing conclusions.

AHP is a multi-objective decision making approach that provides a convenient set of mathematical tools to identify an optimal alternative given a set of competing objectives. One of the major advantages of the AHP is that the analysis does not always require statistically significant sample size. AHP uses a number of pairwise comparisons between quantitative or qualitative criteria to assess the relative importance of each criterion. These can be arranged in a hierarchical manner known as a 'value tree' for sets of attributes, and qualities (levels) within these attributes. The simplicity of AHP approach is that, unlike other 'conjoint' methods, the qualities (or levels) of different attributes are not directly compared. The AHP approach thus removes the need for complex survey designs and can even be applied (in an extreme case) with only a single respondent. As the input data in AHP analysis is based on expert's perceived judgment, a single input usually represent a group of representatives in the sample data. Other conjoint methods such as choice experiments do not realise statistically robust results unless there is a sizable number of usable survey responses. Most of the conjoint analysis place quite a high 'cognitive burden' on respondents in that they are asked to make comparisons across options that have a large bundle of attributes and levels of these attributes. In contrast, under AHP, respondent are not asked to make choices between all criteria and thus respondents are less likely to adopt mental short cuts by concentrating disproportionately on one attribute or level (Saaty, 1980).

Measuring Consistency in Judgments

In the application of AHP, inconsistency in pairwise comparisons may be introduced as a result of a number of factors such as lack of adequate knowledge, improper conceptualisation of hierarchy and even lack of statistically significant sample size etc. A consistency ratio is generated for each prioritised scale upon completion of carrying out the pairwise comparison. It is used to determine the consistency of the judgments. The consistency ratio is defined as the consistency index for a particular set of judgments divided by the average random index as shown in following equation.

$$CI = {(\lambda \max - n)} \big/ {(n-1)} \quad \text{and} \quad CR = {CI} \big/ {RI}$$

Where, λ_{max} is maximum eigenvalue, n is size of the judgment matrices, *RI* is random index. The values of *RI* for different size of judgment matrices are found in existing literatures.

Based on the various numerical studies, Saaty (1980) stated that to be acceptable (ie. for tolerable inconsistency), the CR must be less than or equal to 0.10 (irrespective of the nature of the problem); if this condition is not fulfilled, a revision of the comparisons is recommended. Perfectly consistent judgments would be represented by a consistency index of zero, the same as the consistency ratio. It must be stressed, however, that an acceptable CR does not guarantee a good final selection outcome. Rather, it ensures only that no intolerable conflict exists in the comparison made, and that the decision is logically sound and not a result of random prioritization (Doloi, 2008).

AHP Framework and the attributes associated with coastal regions

In the AHP method, the first step is to set up the objective of decision making (Saaty, 1983). In this research, the objective is to determine what attributes impact the issues that were identified in relation to management of coastal regions and how important the individual attribute are for achieving the optimal management strategy in coastal zone management. Therefore, the main objective, '*sustainable management strategy*' should be placed at the top in the analytical hierarchy framework.

A total of 22 criteria were selected to cover breadths and depths of identified issues important to the management of coastal regions. Table 9 describes all the 22 criteria and shows the respective impacts in terms of three impact areas: *Social*, *Economical* and *Environmental*. Each of these criteria was further sub-divided into 11 sub-criteria based on the potential impacts. While using the 22 criteria, 11 sub-criteria and five alternative strategies in the hierarchical framework, the questions for pairwise comparison for AHP were far too many (in the order of 500 questions). Table 10 describes all the 11 sub-criteria and three representative groups used in the hierarchy for multi-criteria analysis. During the pilot implementation, it was found that the questionnaire of this length will neither practical nor feasible for respondents to respond voluntarily. Thus, the overall problem has been broken down into two hierarchy for simplicity. Based on the perceived responses from brain storming workshops, the 11 subcriteria have been grouped into three representative categories namely Sea Level Rise (SLR), Short Term Flooding (STF) and Overall Climate Change (OCC). The first hierarchy has been developed incorporating all 22 criteria and three sub-criteria. In order to evaluate the impacts of risks associated with all the criteria and the sub-criteria, the main objective "Risk Effect in Macro Level" was placed at the left most level in the three level hierarchy as shown in Figure 6.

The second step is the break down the objective into criteria and sub-criteria and organise them within an analytical hierarchy. As stated earlier, the second level hierarchy was divided into 22 main criteria as shown in the figure. The decomposition of the criteria to the next level is performed by identifying three sub-criteria groups. There is no single correct hierarchy for a given system, and several different hierarchies can be built depending on difference perspectives. A hierarchy of objectives, criteria and sub-criteria is constructed in order to gauge the extent to which each option contributes to the fulfillment of the overall objectives.

Table 9: Criteria for MCDM Analysis

Criteria	Description	Impacts (S, E, Ev) S- Social, E- Economic, Ev-Environmental
Drainage (D)	Structural and non structural elements associated with drainage infrastructure	S, E, Ev
Roads (RD)	Structural and non structural elements associated with road infrastructure	S, E, Ev
Railways (RW)	Structural and non structural elements associated with railway infrastructure	S, E, Ev
Port and harbours (PH)	Structural and non structural elements associated with port and harbour infrastructure	S, E, Ev
Dykes (DK)	Flood protection dykes and associated structures	S, E, Ev
Coastal Protection Structures (CPS)	Structural and non structural elements associated with coastal protection structures	S, E, Ev
Landuse Planning (LP)	Landuse planning for improvement and developments	S, E, Ev
Residential building (RB)	Buildings used for residential purposes	S, E, Ev
Non residential building (NRB)	Buildings used for commercial and institutional purposes	S, E, Ev
Potable water (PW)	Potable water and associated infrastructures	S, E, Ev
Water quality (WQ)	Allowable standard for water quality	S, Ev
Erosion (E)	Extend of erosion due to flooding, sea level rising or other associated factors	S, E, Ev
Tourism (T)	Tourism related infrastructure including service delivery	S, E, Ev
Population: Short term displacements (PSD)	Short term population displacements resulting from temporary disturbances such as short term flooding and other natural disasters	S, E, Ev
Population: Long term displacements (PLD)	Long term population displacements resulting from temporary disturbances such as long term flooding and other natural disasters	S, E, Ev
Agriculture (AG)	Agricultural lands and produces	S, E, Ev
Fishery (F)	Fishery infrastructure including both structural and non structure elements	S, E, Ev
Fish habitat/distribution(FH)	Fish habitats and distributions	S, E, Ev
Wetland health extent (WE)	Extents of wetland	S, Ev
Flora biodiversity (FLB)	Flora biodiversity along the coastal regions	S, Ev
Fauna biodiversity (FAB)	Fauna biodiversity along the coastal regions	S, Ev
Mangrove (MG)	Mangrove along the coastal regions	S, Ev

Table 10: Sub-Criteria for MCDM Analysis

Categories	Consequences or sub-criteria	Description/Impacts
1. Sea Level Rise 2. Short Term Flooding 3. Overall Climate Change	Depth	Water depth resulting from flood
	Duration	Flood duration
	Velocity	Water velocity resulting from flood
	Frequency	Frequency of occurrence of flood events
	N	Nitrogen
	NO2	Nitrogen dioxide
	NO3	Nitrogen trioxide
	TP	Total phosphate
	PO4	Phosphate
	Salinity	Increased in water salinity due to sea level rise
	Turbidity	Water turbidity due to flood

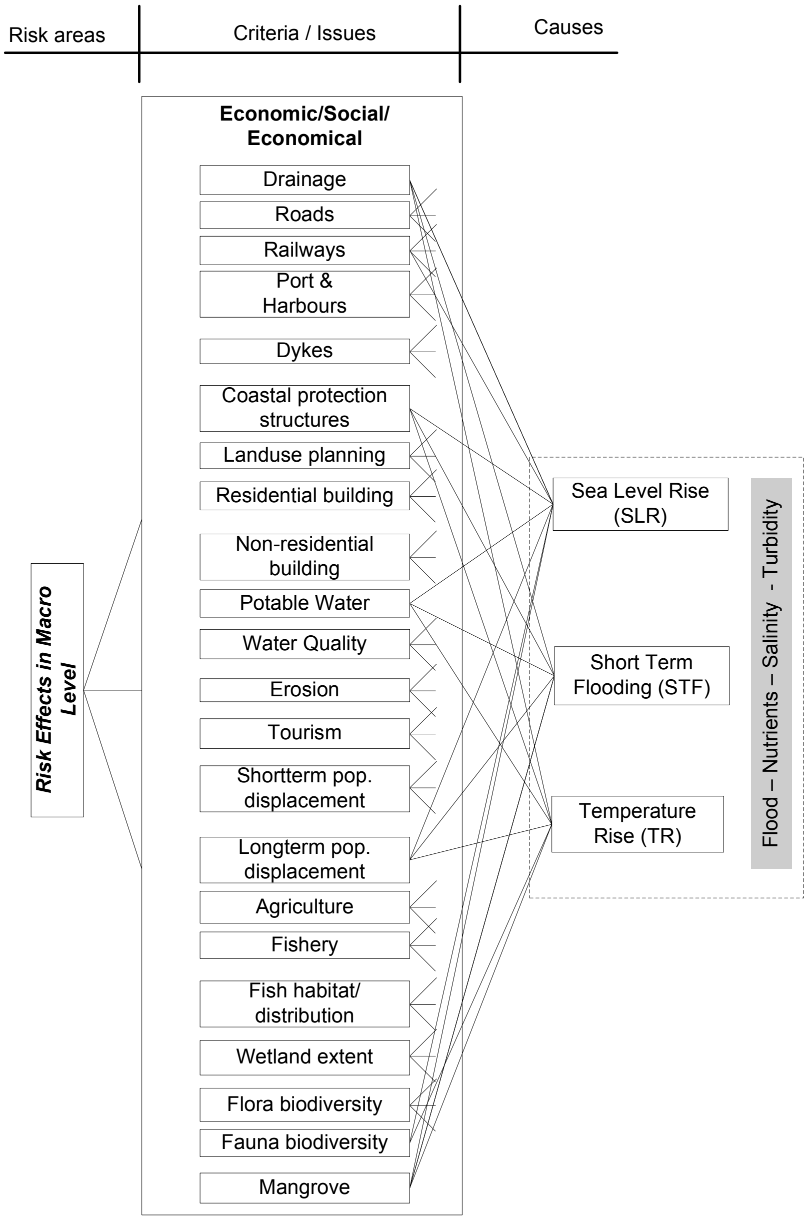


Figure 6: Hierarchy for determining risks across the identified issues

Framework for analysis of alternatives

Figure 7 shows the hierarchy comprising all three sub-criteria groups and the five identified strategies. The main objective of this hierarchy is to identify the "Sustainable Management Strategy" and this it is placed at the top of the hierarchy as shown. The next level is the three sub-criteria groups followed by the five alternative options or strategies at the bottom of the hierarchy.

Table 11 shows five alternative strategies to make appropriate comparison relative to the criteria and sub-criteria. It is worthwhile to mention that all these initial criteria, sub-criteria and the alternative management strategies were developed based on country based PRG meetings and project planning workshops held in Bangkok in November 2007.

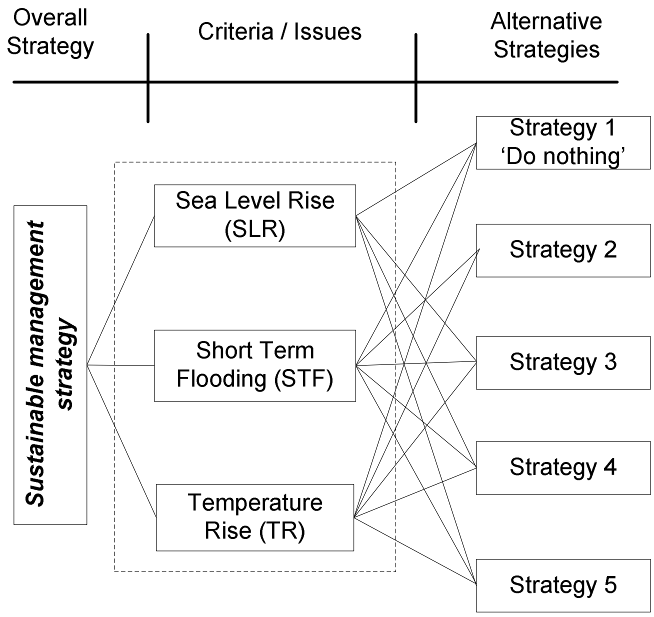


Figure 7: Hierarchy for determining sustainable management strategy

Table 11: Strategies for sustainable management

Strategy	Description	Explanation
Strategy 1	No Intervention Required	No intervention required refers to no action and continue with business as usual.
Strategy 2	Investment in Structural Measures	This includes construction of dykes, coastal protection structures and other structural measures.
Strategy 3	Investment in Nonstructural measures	Investment in Nonstructural measures/ Capacity Building (Individual, Institutional, Community, Organisational, National, Investment in R&D
Strategy 4	Effective Implementation of Existing Policies	This includes revisiting the existing strategies and their implementation strategies in the context of current changed environment due to climatic variations and extreme conditions.
Strategy 5	New Policy development	This includes revisiting the existing policies and their implementation strategies in order to devise an appropriate policy in the context of current changed environment due to climatic variations and extreme conditions.

Survey Design

A pilot survey was conducted to measure how the decision makers perceive the relative importance of the identified functions associated with sustainable management in the hierarchy as shown in Figures 6 and 7. The questionnaire was designed as a tool for assessment of the differing levels of criteria that provide the alternatives for the AHP model. In a questionnaire survey approach, there are several ways of including the views and judgments of each respondent in the priority setting process. In a common objective context where all respondents have the same objectives, there are four ways to set the priorities: 1) consensus; 2) vote or compromise; 3) geometric mean or the individuals' judgments; and 4) separate models or players (Dyer and Forman, 1992).

The survey was conducted using web-survey tool. A nine point likert scale was used in each question for respondents to indicate a preferred response. The compositions of the questions included in the questionnaire are aimed at gaining responses that provide increased clarity to the issues regarding adaptive management of consequences due to climate change. The available answers to the questions provide a spectrum indicating the relative importance of each particular issue. A decision maker can express a preference between each pair of criteria as equal, moderate, strong, very strong and extremely preferable (important). The choice to remove the possible selection of neither agrees nor disagrees provided the respondents with a clear choice of judgment. With reference to the responses provided in the basis questions, the same likert scale was used to compare the elements of each level of hierarchy with one another in pairs in relation to their respective 'parents' at the next higher level. The nine point scale is shown in Table 12. Respondent's emphasis and selections directly determine the weighting of the evaluation criteria used in the matrix of the analytical hierarchy process and hence achieved the effectiveness in the data analysis.

Table 12: AHP pairwise comparison scale

Value rating for judgment	**Linguistic judgment**
1	Elements are equally preferred
3 or (1/3)	One is moderately preferred to the other
5 or (1/5)	One is strongly preferred to the other
7 or (1/7)	One is very strongly preferred to other
9 or (1/9)	One is extremely preferred to the other
Note: 2,4,6,8 are intermediate judgmental values between adjacent scale values	

Determination of the Relative Important Index (RII) for developing the judgment matrices

The Relative Importance Index (RII) is found to be an important measure for establishing the initial judgment matrices among the criteria and sub-criteria in the hierarchy framework (Doloi, 2007). In order to rank the criteria and the sub-criteria in the order of their criticality, the mean scores of responses for different project attributes can be calculated and interpreted using descriptive statistics from the questionnaire. However, Chan and Kumaraswamy(1997) suggested that the mean and standard deviation of each individual attribute is not reliable statistics to assess the overall rankings because they do not reflect any relationship between them. Hence, all the numerical scores of each of the identified factors were necessary to transform to relative importance indices to determine the relative ranking of the attributes. The relative ranking of the attributes can be evaluated based on the Relative Importance Index (RII), which is evaluated using the following formula (Chan and Kumaraswamy, 1997; Iyer and Jha, 2005).

Relative Importance Index $RII = \frac{\sum wI}{AxN}$; $(0 \leq RII \leq 1)$

Where 'w' is the scale index (in the range of 1-9) used by the respondents to respond to their selection and 'I' is the respective number of respondents selecting the same index. 'A' is the highest weight in the likert scale (which is 9) and 'N' is the total number of respondents responded to the given question in the sample. The highest RII values indicate the most critical attributes, the lowest values indicate the less significant attributes which then provide a sound basis to establish the initial judgment matrix.

3. Study Areas

The following six coastal areas were selected from the six participating countries in the Asia Pacific region. The geographic locations of these study sites are shown in Figure 8.

Figure 8: Locations of the study areas in 6 countries

1) Gippsland Coastal Region, Australia : The Gippsland coast is home to thousands of people who live in or near one of the many coastal towns and settlements located between San Remo on the eastern extent of Western Port Bay and Mallacoota near the New South Wales border. Away from these built up areas, the Gippsland coast remains in a largely natural state, being characterized by diverse natural and cultural values, and including important habitat for a range of fauna species protected by National Parks, reserves and public foreshore land (GCB, 2008). The coast includes the Gippsland Lakes System which is a series of coastal lagoons – large areas of shallow water that have been almost wholly sealed off from the sea by a coastal dune system.

2) South West Region Bangladesh**:** The area is low-lying deltaic plain and is characterized by wide rivers and estuaries that allow sea water to propagate faster and to intrude far inland (Barua, 1991). The study area comprises an area of 32,280 sq. km between latitude 21˚30' N to 24˚00' N and longitude 88˚50' E to 90˚10' E. The area has four distinct seasons. The monsoon and the dry season are the main seasons. The monsoon lasts approximately from June to September. More than 90% of total annual rainfall occurs during this period where the annual average rainfall is 1,700 mm/year (ADB, 2005). The area is bounded by Ganges River in the north, tributaries from Meghna River in the east, international boundary in the west and the Bay of Bengal in the south. The topography of the region is rather flat, and gently sloping towards the Bay of Bengal. Most of the area is protected with polders against river flooding. The downstream part of the area is covered with Sundarban forest. The part of Sundarban forest in Bangladesh occupies a land area of 6016 sq.km, of which rivers, streams and channels occupy 1,874 sq. km. About 70% of the Sundarbans is land and 30% is water. In order to prevent cyclonic or storm-surge flooding and to increase crop production by preventing intrusion of saline ocean water, many coastal embankment projects were initiated in the 1960s by the Bangladesh government. In coastal and near-coastal areas polders protect against saline water intrusion and tidal flooding, and to some extent against cyclonic flooding and tidal surges.

3) Kushiro Coastal Region, Japan: Kushiro wetland located on the eastern side of Hokkaido is the largest wetland in Japan registered by the Ramsar treaty and the coastal area is highly developed for industrial purposes. The main river flowing through Kushiro wetland is Kushiro River whose length is 154 km and the river basin area is 2510 km^2.The incline of the Kushiro wetland area is relatively gentle. The human population in this highly developed coastal area is about 230,000. In recent years, changes in water circulation and mass transport have been considered problems which damage the ecological systems of the wetland.There is significant potential for damage in the Kushiro coastal region from disastrous storm surges or flood events.

4) Colombo, Sri Lanka: Climate change has clearly affected the weather pattern of Sri Lanka and this is evident in the climatological measurements of the last 3 - 4 decades. Overall rainfall has not shown a significant change in most parts of the country while some other indicators such as the length of rainy spells and average rainfall per spell have clearly changed; and studies show that the rainfall intensity has increased (Herath and Ratnayake, *2004*; Ratnayake and Herath, 2004). More frequent rainfall induced disasters such as landslides and floods in the recent past can be attributed to this increase in intensity of rainfall. Colombo, the capital city and financial hub of Sri Lanka, is one of the major coastal cities adversely affected by the floods. Colombo received two occurrences of its record highest rainfalls in the last two decades. Such frequent extreme events have focused the attention of the public and have forced the authorities to attempt mitigating works. Several drawbacks of the current management system have been identified and among the technical aspects the inadequate capacities of the drainage networks, loss of flood retention spaces and poor management is highlighted. The Colombo floods result in heavy economic losses, mainly due to two factors. The poor existing drainage facilities with inadequate drainage capacities are the main reason for floods when heavy rains occur in the city area. The other factor is the overflowing of the Kelani River which flows through the northern parts of the city.

5) Bangkok and Gulf of Thailand: Bangkok, the capital city of Thailand, with latitude 13° 45' N and longitude 100° 31' E, is one of the larger cities in Asia and is a regional hub. It is located on the lower flat basin of the Chao Phraya River, the largest and most important river in Thailand which has a drainage area of 160,103 km^2 and an annual suspended sediment discharge of $11x10^6$ tons. It originates in the northern most part of Thailand and discharges to the Gulf of Thailand after flowing approximately 1,200 km. The average annual discharge is about 770 m^3/s with a peak of 4,560 m^3/s recorded in 1995 (Thammasittirong, 1999). The coastal environment of the Chao Phraya delta is classified as low-energy micro-tidal. Somboon (1992) showed that the shoreline has migrated about 90 to 100 km southward from the center of the central plain in

Thailand over the last 6000 years, which corresponds to a migration rate of about 15 m yr^{-1}. Bangkok has a hot and humid tropical climate; the hottest month is April with average maximum temperatures of 35°C and average minimum of 26°C, while December is the coolest month with average maximum temperatures of 31°C and average minimum of 21°C. The rainy season spans May to October, and the average annual rainfall in Bangkok is 1500 mm. Floods, mainly caused by upstream inflow and high intensity rainfalls, are the most frequent natural disasters in Bangkok. They affect a large number of people and cause huge economic damage almost every year. Due to its low elevations, ranging from 0 m to 4 m above mean sea level, tidal effect is prominent in the Chao Phraya river up to several kilometers inside Bangkok and that contributes significantly to floods. There are usually two high and two low tides per day in the Gulf of Thailand, but these are often asymmetrical with amplitude of 1-2 m. The daily variation of tides is normally from -0.5 m to 1.5 m with a peak of 2.5 m recorded in 1995. For Bangkok, the steady rise in sea level poses a threat for the investment, operation and safety levels of the flood-control system, which could have an estimated annual pumping cost of up to US$20 million (Sabhasri and Suwarnarat, 1996). The Fourth Assessment Report of IPPC (IPCC-AR4) has highlighted the grave consequences of sea level rise including catastrophic floods to several low-lying coastal cities around the world including Bangkok (IPCC, 2007).

6) Nam Din Coast, Vietnam: Nam Dinh coast is one of the most populated coasts in Vietnam. It has the most fertile soil in Vietnam, very suitable for rice cultivation. The coast is suitable also for other marine related economic activities such as salt production, fishing, shrimp and fish farming etc. Additionally, the area is located near Hanoi, the Capital City of Vietnam and some of its beaches have become recreation sites for Nam Dinh and Hanoi City dwellers. The Nam Dinh coast has been formed by the deposition of sediment from the Red River with its four branches, the main river, the Ninh Co River, the Day River and the So River. The sediment from the river consists mainly of silt and fine sand. Thus, near the river mouth, deposition of silt and fine sand has enabled the development of mangrove forests. There are very wide mangrove forests, such as the Giao Thuy and the Nghia Hung mangrove forests. There are several distinct ecological systems in the area such as the marine ecological system, the mangrove forest ecological system and the estuarine ecological system. Thus, the coast is ecologically very diverse. Recently, with economic development, a port was constructed in the Ninh Co River estuary. Industrial developments, such as ship building and thermal power generation are proceeding. At present, the coast is facing serious environmental problems, the first being accelerating erosion. At the place with most serious erosion, the coast has retreated about 2km. forcing many local people to relocate inland. This is a densely populated area with extensive economic activity, and the natural hazard causes large economic losses.

4. Results & Discussion

The three different tools of the integrated modelling framework developed in this project have been applied independently in different case study areas in different stages based on availability of data and resources. The detailed case study applications and the key findings of those case study applications (Table 13) have been presented in the proceedings of the International symposium on *Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies* as a part of this project (Dutta and Wright, 2010).

Table 13: Various case study applications of the integrated tools included in Dutta and Wright, 2010.

Tool	Case study countries	Reference papers in Dutta and Wright, 2010
Process model	Australia, Bangladesh, Japan	Australia (Kabir & Dutta, 2010; Alam & Dutta, 2010) Bangladesh (Bhuiyan & Dutta, 2010) Japan (Nakayama et al., 2010)
Impact Assessment Tool	Australia, Japan, Sri Lanka, Thailand, Vietnam	Australia (Dutta et al., 2010) Australia, Japan, Sri Lanka, Thailand, Vietnam (Wright et al., 2010)
MCDM Tool	Australia, Bangladesh, Japan, Sri Lanka, Thailand, Vietnam	Doloi, 2010

In this section, results of several selected case study applications of different components of the integrated tool are presented.

4.1 Application of the Salinity Model in South West Coastal zone of Bangladesh

The study area consists of 129,120 square grids of 500 m size. The heights of the existing polders have been added with the topography to represent the river bank protection. For river network, the Gorai river and its tributaries are considered. Three hourly discharges at Gorai Railway Bridge and Tahirpur stations are used as upstream boundary and the three hourly water level data at Charduani and Hironpoint are used as downstream boundary. Daily rainfalls at 24 gauging stations are used as internal runoff. No lateral overland flow is considered. The river network included cross-sections at every 500 m interval between Gorai Railway Bridge and Bay of Bengal. The roughness coefficients for surface were estimated on the basis of the land use types (Dutta & Nakayama, 2009). Upstream discharge, daily rainfall and 3 hourly water levels at different gauging stations have been collected from the Institute of Water Modelling (IWM).

The hydrodynamic model has been calibrated and verified for two events of the year 2002. The month of April-May is used for calibration and November-December for verification. The calibrated parameter is manning's roughness in the river. Calibration and verification were performed using the water level data at some selected stations. The roughness coefficients were adjusted by trial and error. The coefficients were found to be within 0.015-0.035. Figures 9 and 10 show the comparison of simulated and observed water level at Kamarkhali and Patgati where the water levels are measured based on the datum of the Public Works Department (PWD) of Bangladesh. The PWD datum is 0.46 m lower than the mean sea level.

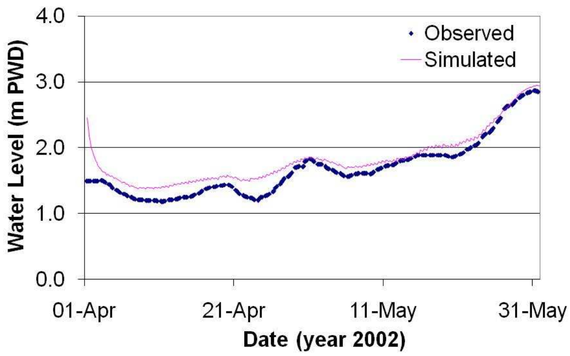


Figure 9 Kamarkhali water levels during calibration

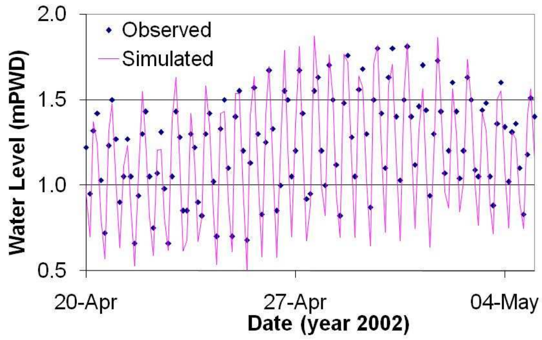


Figure 10 Patgati water levels during calibration

For verification of the model parameter, flow during the month of November and December in the year 2002 has been considered. The simulated water levels show good correlation with the observed data. Figures 11 and 12 show the comparisons of water level at Kamarkhali and Patgati for verification period.

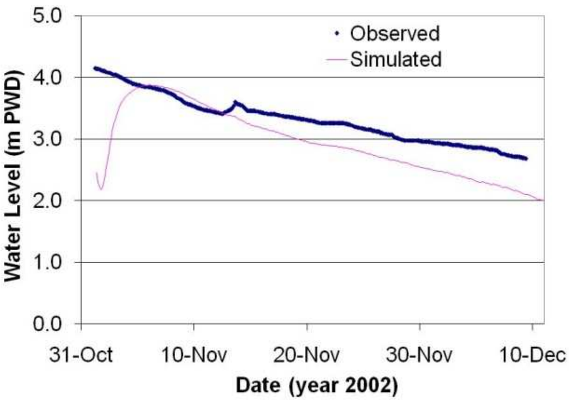


Figure 11 Kamarkhali water levels during verification

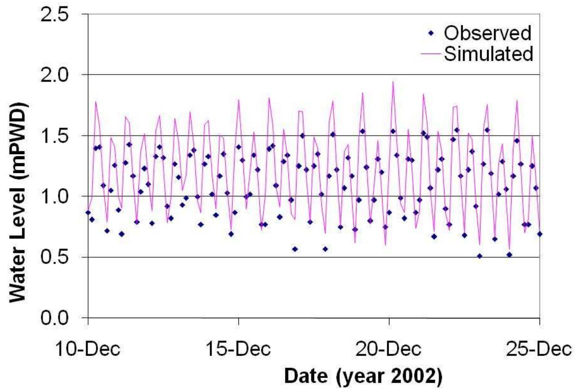


Figure 12 Patgati water levels during verification

The model performance was determined based on mean and coefficient of determination (R2). The computed mean value at Patgati and Pirojpur were found to be almost the same as the observed mean values, with a variation of + 6% and + 9% respectively. The values of the coefficient of determination (R2) between the observed and computed hydrograph of water level were found to vary from 0.81 to 0.91, while this value should be 1 for perfect agreement. The scatter plots of water level data for different strategies have been shown in figures 13 and 14.

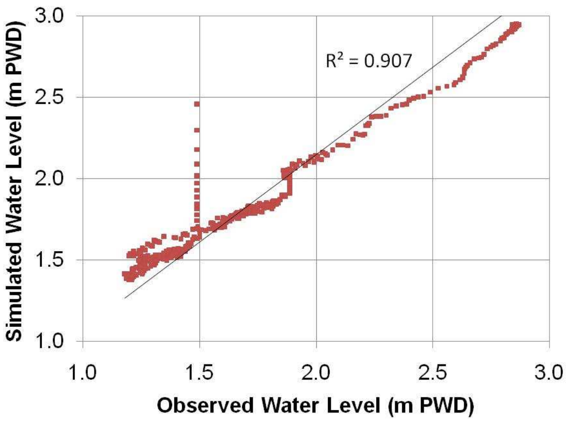


Figure 13 Scatter plot of Kamarkhali water level

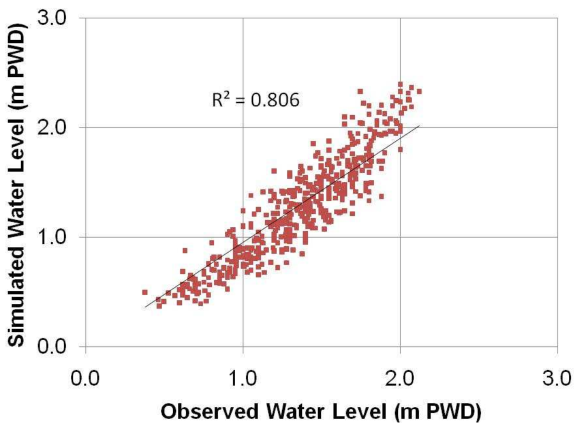


Figure 14 Scatter plot of Patgati water level

The salinity model has been calibrated by adjusting values of dispersion coefficient in the river (Gates et al., 2002). Figure 15 shows the comparison of observed and simulated salinity at Mongla station where the unit is parts per thousand (ppt).

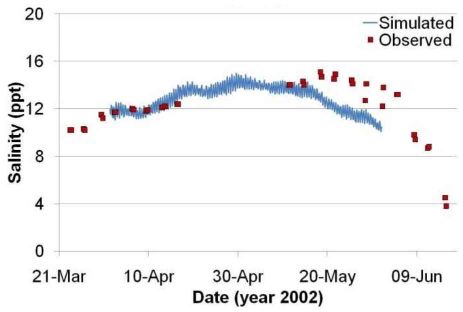


Figure 15: Salinity comparison at Mongla in calibration

Sea Level Rise Impact

Due to sea level rise and considering same salinity at sea, the changes in maximum salinity at several stations have been summarized in the following table (Table 14).

Table 14: Changes in maximum salinity due to 59 cm SLR

Name of Station	Without SLR (ppt)	With 59 cm SLR (ppt)	Salinity Increase (ppt)
Mongla	14.9	15.7	0.8
Nalianala	16.3	17.0	0.7

The intrusion of salinity which is associated with salinity increase has been determined in the Passur river for different salinity front line and summarized in the following table (Table 15);

Table 15: Salinity intrusion length in Passur river

Salinity front line (ppt)	Salinity intrusion length (km)
5	25
10	7

The long profile of maximum salinity along the river length in Passur river with and without SLR has been shown in the following figure (Figure 16).

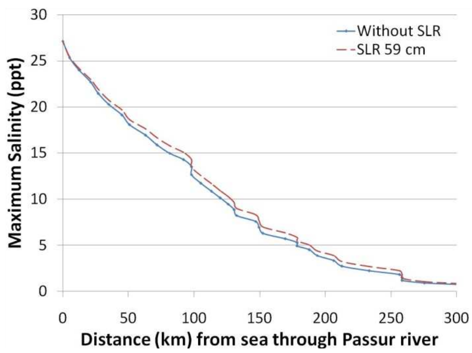


Figure 16: Long profile of salinity along the Passur river

Flood maximum depth for sea level rise condition has been shown in Figure 17. The scenarios used are with and without existing polders.

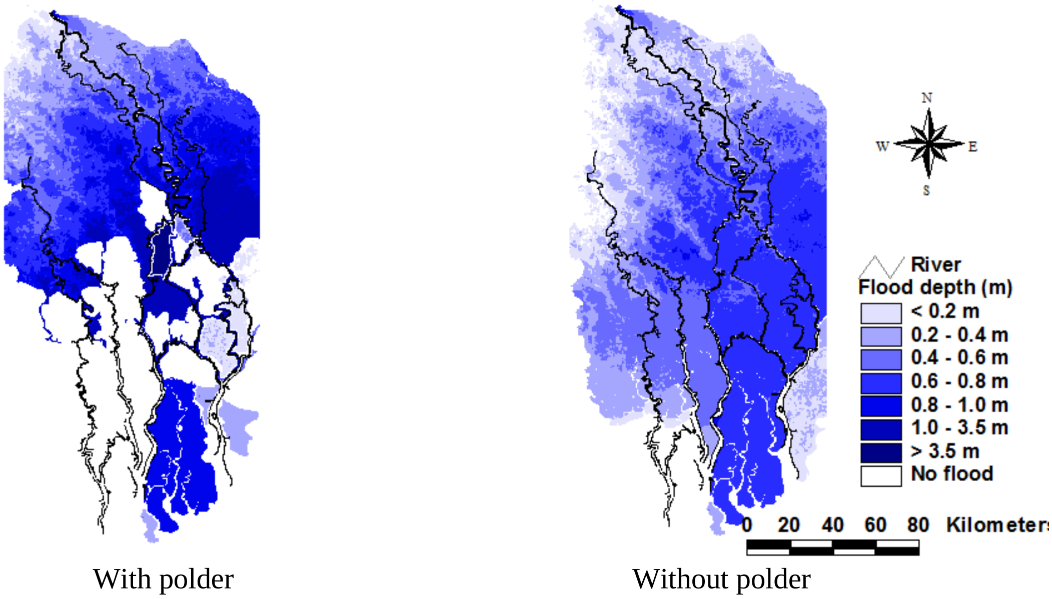


Figure 17: Flood maximum depth for 59 cm SLR with and without existing polders

4.2 Application of the Sediment Dynamics Model in Gippsland Lakes Catchment

Latrobe River basin, a major basin of the Gippsland Lakes catchment region, is located in the south-eastern part of Victoria, Australia as shown in Figure 18. The main stream of this watershed is Latrobe River, which flows eastwards throughout the whole basin and ultimately discharges into Lake Wellington. The central part of this basin is less elevated and covered with elongated flat farmland with unconsolidated soils, which are very much susceptible to bank erosion (DPI 2009). The other parts excluding central region consist of steep mountains with fairly dense forest. The basin includes the three major towns of Moe, Morwell and Traralgon along its central part. The total basin area is around 4,675 Km^2 and it sustains a population of 97,339.

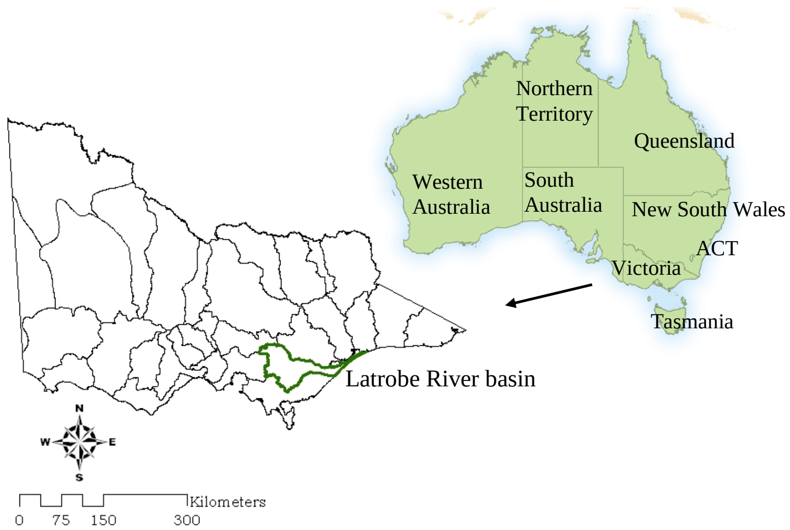
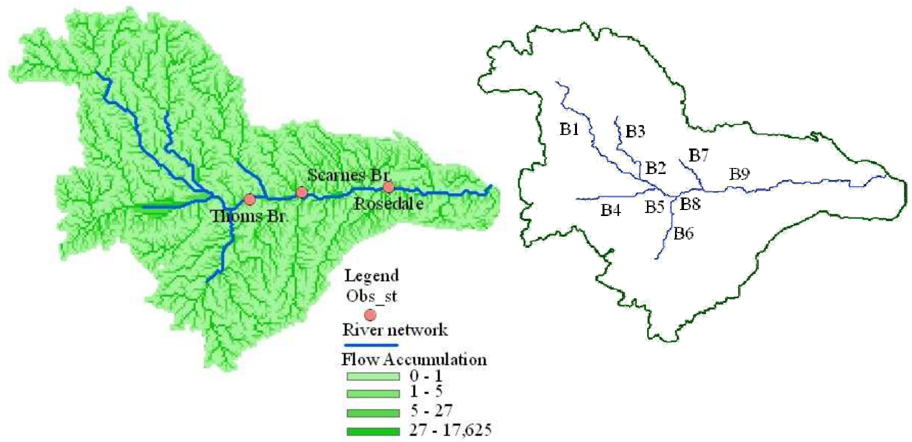


Figure 18: Latrobe river basin location in Victoria, Australia

Historical Event Simulations

In this study, the Latrobe River basin has been simulated for different climate change conditions with respect to the base period of 2007 flood event. Prior to describing climate change effect in the next section, the model setup and simulations for 2007 flood case have been repeated here in this section. The digital elevation model (DEM) of *500-m* grid spacing has been used in simulation which was originally taken from SRTM data of *90-m* resolution. The flow accumulation map and the major river network which has been generated from SRTM DEM are shown in Figure 4a. Rosedale, Scarnes Bridge and Thoms Bridge are the three gauging stations along the river network, which have been selected for calibration and verification of the model application. The maximum temporal resolution has been set to *1-hr* during model simulation. The model stability checking and temporal resolution refining have also been carried out based on the satisfaction of courant condition. Roughness coefficient (*n*) values and an index of soil detachability (*k*) have been considered main calibrating parameter in this modeling. The major river network has been described by hydraulic parameters associated with each of river branches to capture river flow dynamics properly. The different branches of Latrobe River have been defined separately in this study as shown in Figure 19b.



(a) *(b)*

Figure 19: Flow Accumulation Map and river network for Latrobe River basin modeling

Figure 20 shows the total water budget allocation during 2007 flood periods based on simulation results of different hydrological modules. It implies that a higher interception and evapotranspiration rate in Latrobe River basin minimizes the amount of overland flow into the river systems.

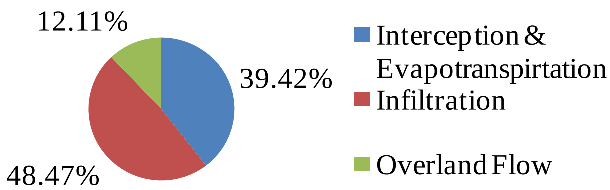


Figure 20: Water budget allocation in Latrobe River basin (Jun-Aug, 07)

In 2007, the flood hydrographs in different stations revealed multiple peaks during June to August. It has revealed that a runoff coefficient of 0.2 allocates water distributions properly for hydrological simulations at Latrobe River basin when the basin antecedent soil moisture content is high. Since the basin has a high soil moisture capacity that triggers a high infiltration rate (Potter et al., 2005) and on the other hand, a constant runoff coefficient has been planned to use instead of sub-surface simulations, the flood events in August, 2007 have been chosen to analysis which occurred due to rainfall with wet soil moisture antecedent conditions.

August, 2007 flood events have been simulated well with using the constant runoff coefficient. Figure 21 shows water and suspended sediment discharges at Rosedale and Scarnes Br. respectively with basin average rainfall. The model well simulated daily water discharges and the correlation coefficients (R-squared values) 0.935 and 0.876 at Rosedale and Scarnes Br. respectively are found in between simulated and observed daily water discharges as shown in Figure 22. Table 16 presents the highest and lowest Nash-Sutcliffe's coefficient of 0.926 and 0.830 respectively between simulated and observed daily water discharges at different river gauging stations during the flood event August, 2007.

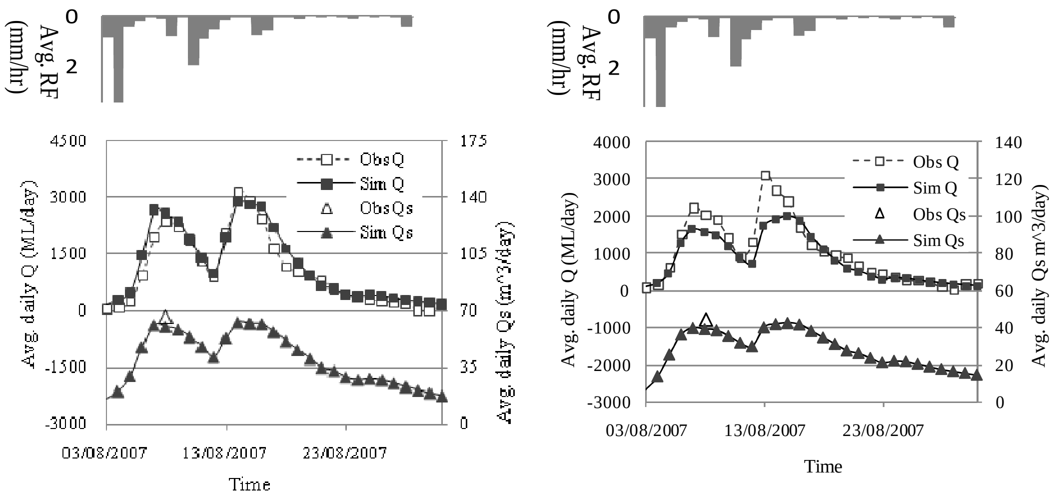
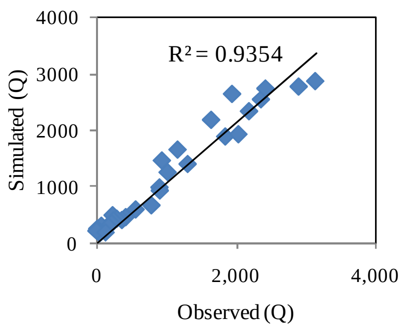
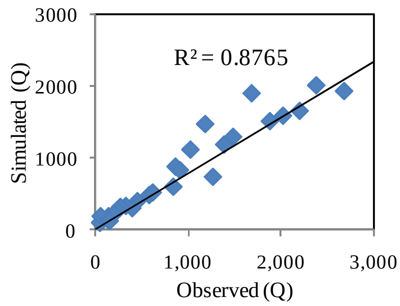


Figure 21: Water and suspended sediment discharges with basin avg. Rainfall



(a) At Rosedale



(b) At Scarnes Br.

Figure 22: Comparison of simulated water discharges at Latrobe River

Table 16: Evaluation of hydrological simulation of Latrobe river basin modelling

Items	Stations	Nash-Sutcliffe COE
Avg. daily, Q	Rosedale	0.926
	Scarnes Br.	0.830

The suspended sediment discharges at Rosedale and Scarnes Br. are found to follow a similar trend as on the water discharges along the river ways. A relatively smaller portion from eroded soils from hillslope area reaches to the river systems due to less overland flow. On the other hand, many reservoirs along the river courses caused a decrease of flow velocity which promotes large particle sized sediment deposition. It is worth noting here, usually grains smaller than 0.125 mm always behave as suspended sediment while grains coarser than 8 mm travel as bed load (Wilcock, 2004). But, these limits are highly variable with flow strength. Analyses of observed data revealed that the water discharges at Latrobe River delivered a limited force to channel systems during the flood events August, 2007 and in these circumstances, the suspended sediment concentration ranges were within the threshold limits of using the Govers transport capacity equation. Therefore, simulated suspended sediments are found to be similar by comparing with a single observed data as described in Table 17. Analyses of model results in this study area with more observation data are now underway.

Table 17: Evaluation of simulated suspended sediment results

Items	Stations	% of deviation at single obs.
Avg. daily, Qs	Rosedale	+9.73
	Scarnes Br.	+12.3

Assessment of Climate Change Conditions

In this study, process-based sediment dynamic modelling on Latrobe River basin has been carried out under climate change conditions considering the base flood event in August, 2007. The climate change conditions have been represented through 1) increasing rainfall intensity; 2) reducing forest areas (exposing more bare lands); and increasing soil erodibility as per the case of presence of ashes after bushfires. Figure 8 shows water and suspended sediment simulations at Rosedale station, Latrobe River basin under different climate scenarios. Table 18 summarizes the outcomes of all the simulations in terms of numerical values. The results show that daily average sediment discharges will increase 4.14%, 8.14% and 11.74% for 10%, 20% and 30% increase of rainfall respectively with respect to the flood event August 2007. Sediment dynamics in this basin will also be significantly impacted due to the reduction of forest areas. As stated earlier, reduction of forest areas in this region is expected via bushfires which in other way, would increase soil erodibility due to presence of huge ashes. Simulation results for 10%, 20% and 30% reduction of forest areas and same percentile increase of soil erodibility show that sediment yield would be 0.65, 1.74 and 3.53 times higher than the yielding during August, 2007 respectively. It is worth noting here that reduction of forest areas has not been considered in flow simulations. The sediment dynamics would be much worsened in the above climate conditions since reduced forest areas decrease time of concentration which results a higher peak flow. However, a simultaneous effect of these two climate change conditions reveals high amount of sediment yielding.

Table 18: Change in water and sediment discharges (Q and Qs) at Rosedale station under in different climate conditions with respect to the flood event 2007

Scenarios	Avg. Q		Peak Q		Avg. Qs		Peak Qs	
	ML/day	% change	ML/day	% change	m^3/day	% change	m^3/day	% change
a) 10% increase of RF	1351.62	12.45	3324.74	15.51	41.75	4.14	66.35	5.21
b) 20% increase of RF	1498.60	24.68	3848.44	33.70	43.36	8.14	69.82	10.70
c) 30% increase of RF	1644.07	36.79	4348.87	51.09	44.80	11.74	72.77	15.39
d) 10% reduction of forest areas & 10% increase of soil erodibility	1201.93	-	2878.31	-	66.31	65.39	104.94	66.39
e) 20% reduction of forest areas & 20% increase of soil erodibility	1201.93	-	2878.31	-	109.96	174.25	174.50	176.68
f) 30% reduction of forest areas & 30% increase of soil erodibility	1201.93	-	2878.31	-	181.84	353.53	289.90	359.66
g) a+d	1351.62	12.45	3324.74	15.51	69.37	73.01	110.42	75.07
h) b+e	1498.60	24.68	3848.44	33.70	119.53	198.13	193.27	206.45
i) c+f	1644.07	36.79	4348.87	51.09	204.58	410.25	335.01	431.19

4.3 Application of the Nutrient Dynamics Model in Gippsland Lakes Catchment

The Nutrient Dynamics model was also applied in the Latrobe River basin, one of the major river basins of the Gippsland Lakes catchment. The model consists of digital elevation model (DEM) of the surface topography of the basin area. 1 km grid has been used to set up the surface component of the model. Using GIS technique flow direction and flow accumulation maps have been derived to determine the flow paths and used for generating river network system. A sub-catchment based analysis has been carried out for catchment process modelling.

Model calibration

The simulation has been carried out for 7 months period starting from June 2007 to January 2008. During this period river observed a major flood in June-July 07. The model results have been compared with daily observed discharge. However, very few data is available for nutrient and sediment calibration and it is not for all form of nutrients.

The comparison of observed and simulated discharge shows quite acceptable performance of the model in representing the overall shape of the hydrograph and matching the peak (Figure 4). Nash-Sutcliffe model efficiency coefficient is 0.34. The sediment yield comparison has also shows quite accurate prediction at gauge location (Figure 23).

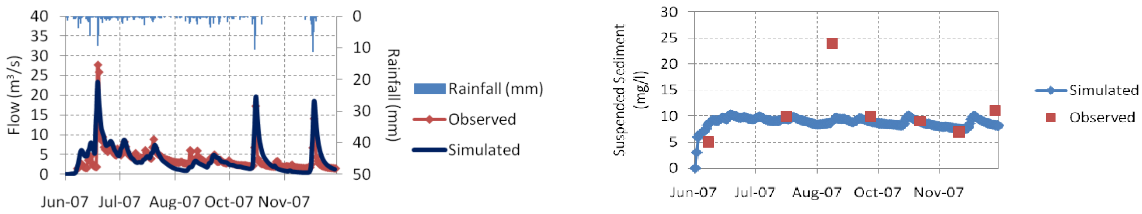


Figure 23: Comparison of discharge (left) and sediment yield (right) at Willow Grove Station

For catchment process modelling the soil moisture index (SMI) has been prepared for the entire simulation period using hydrologic input data. The nutrient generation rate for various land use type has been assumed and considering different transformation rate with SMI the nutrient transformation process has been modeled. The nutrient simulation results have been compared and presented below (Figure 24-25).

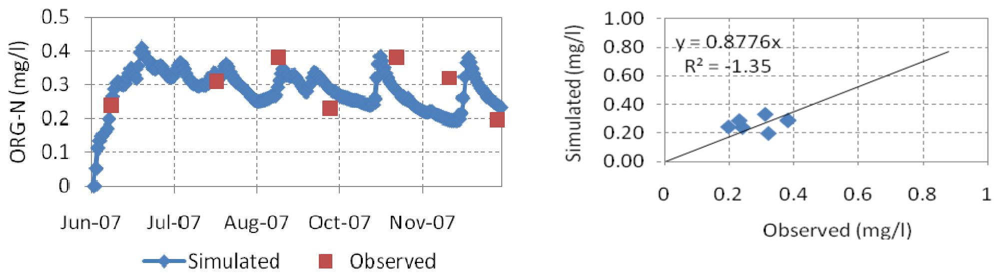


Figure 24: Observed and simulated ORG-N at Willow Grove

The results shown above are considered to be quite satisfactory especially for *NO_3-N* (Figure 25). The root mean square error (RMSE) between observed and modeled result has been tabulated in Table 19.

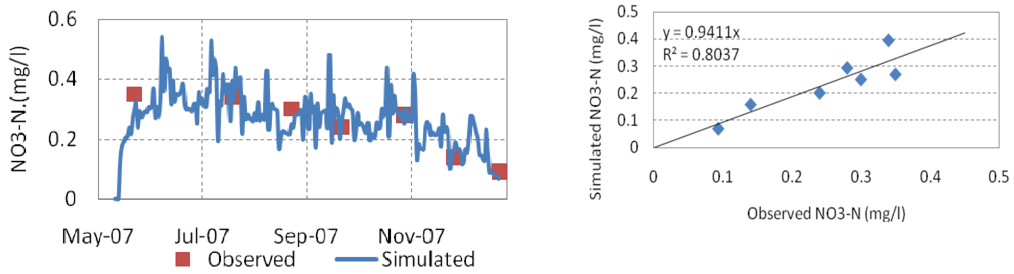


Figure 25: Observed and simulated NO3-N at Willow Grove

Table 19: Calculated RMSE value

	ORG-N	*NO_3-N*	Total *P*
RMSE value	**0.07**	**0.05**	**0.01**

Simulation of climate change scenarios

The climate in Gippsland has observed measureable changes over the last century. The average temperature has increased by 0.8 °C and annual average rainfall is likely to decrease (Brooke & Hennessy, 2005). In a number of studies assessment of climate change in Gippsland region has been found (Brooke & Hennessy, 2005; CSIRO and BoM, 2007; Jones & Webb, 2008). Table 20 shows the projection of changes in temperature and rainfall based on IPCC emission scenarios for 2030 and 2070.

Table 20: Projection of climate change (rise and fall) in Gippsland Region (Jones & Webb, 2008)

	For 2030 (AIB Scenario)	**For 2070 (Lower Emission Scenario B1)**	**For 2070 (Higher Emission Scenario A1F1)**
	Range (10-90%)	Range (10-90%)	Range (10-90%)
Annual rainfall	-8 to 0 %	-12 to 0 %	-22 to 0 %
Temperature	+0.5 to +1.1 °C	+0.9 to +1.9 °C	+1.7 to +3.6 °C

In this study the projections for annual average changes in temperature and rainfall have been applied. Using upper range of change for A1F1 emission scenario following scenarios have been developed for nutrient simulation. These changes have been applied on existing condition i.e. for the simulation period of the model for June 2007 to January 2008.

- *Scenario 1: Effect of 3.6 °C temperature rise on soil moisture condition and nutrient transformation process. Change in Potential evapotranspiration occurs 2-8% increase par degree global warming (Whetton et al., 2002).*
- *Scenario 2: Reduction of rainfall plus the conditions in scenario 1.*
- *Scenario 3: 9% Increase in rainfall (Brooke & Hennessy, 2005) plus the conditions in scenario 1.*

The climate change effects influence the temperature dependant chemical reaction process in the model. The soil nutrient transformation process is related with soil moisture condition, which is dealt with the term soil moisture index *SMI* in the model.

The results have been shown in weekly period moving average plot (Figure 26) for all scenarios and compared with base condition. It is seen that 3.6°C temperature change has significant effects on *NO_3-N* level increasing (Scenarios 1). The peak difference is 0.16 mg/l, which is 30% increase in nitrate level. However, scenarios 2 and 3 did not influence the nutrient level compared to scenario 1. It appears that the change in rainfall did not affect much in hydrologic runoff probably because of using same runoff coefficient for changed hydrologic condition. Accurate representation of the soil moisture condition is crucial for this kind of simulation and more importantly for this type of catchment where the climate is very dry and temperate. It is also notable that the study has only been carried out in small area in upper part of the catchment, so effect could be minor in this area but may have significant impact at the basin downstream.

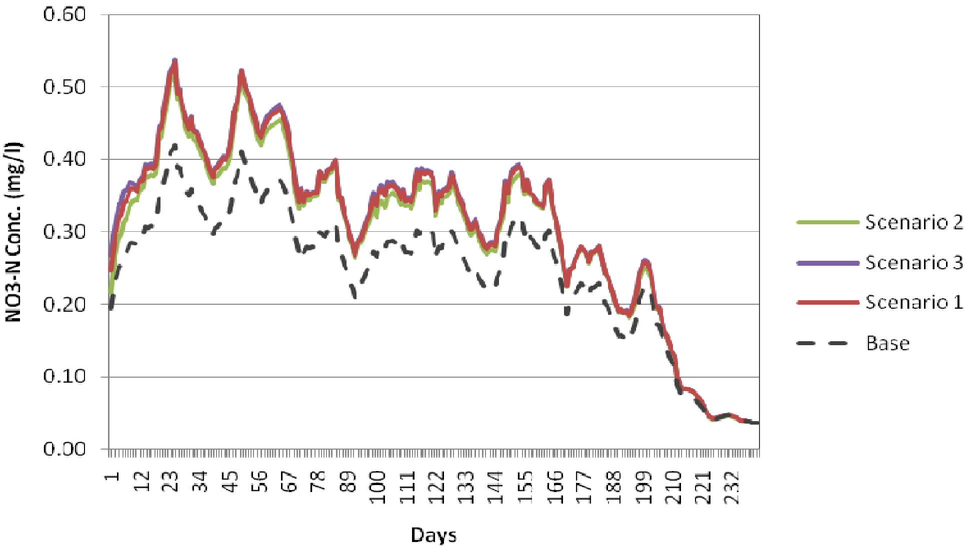


Figure 26: Climate change effects on NO3-N concentration

4.4 Application of the Impact Assessment Tool in Australia, Japan, Sri Lanka, Thailand and Vietnam

Similarity and Differences

Figure 27 presents the scatter plots of Disparity (x-axis) vs. Sensitivity (y-axis) for different hazard parameters against the 22 issues for five countries. Overall, the patterns among different countries are broadly comparable for the various individual hazard parameters, except for Sri Lanka.

For the SriLankan data, disparity was low for all issues and hazard parameters. For the inundation parameter “Depth”, different issues showed similar trends for Japan and Thailand. For Vietnam, more issues showed high sensitivity compared to other countries. For Australia and Sri Lanka, more issues were less sensitive to “Depth” than for the other three countries. The trend was similar for all countries for “Duration” with higher disparity for Australia for more issues than other countries. Similarly, for “Velocity” and “Frequency”, disparity was higher for Australia compared to other countries. In the case of Australia, more issues were less sensitive to “Frequency” than other four countries. For water quality parameters, no issue showed any sensitivity to “Nutrient” for any countries. For Salinity, trend was similar for Thailand, Vietnam and for Japan and Australia. For Turbidity, again trends were similar for Japan and Australia. More issues show higher sensitivity against Turbidity for Vietnam. The agreement was higher for Vietnam and Thailand, compared to Japan and Australia for Turbidity.

These relationships show that in different countries, stakeholders had different perceptions of impacts of flood inundation on various issues. For some issues, there were high levels of agreement compared to other issues. The low disparity for the Sri Lankan data was probably due to the way the questionnaire was administrated, which reflected more of collective, rather than individual, opinion of the stakeholders.

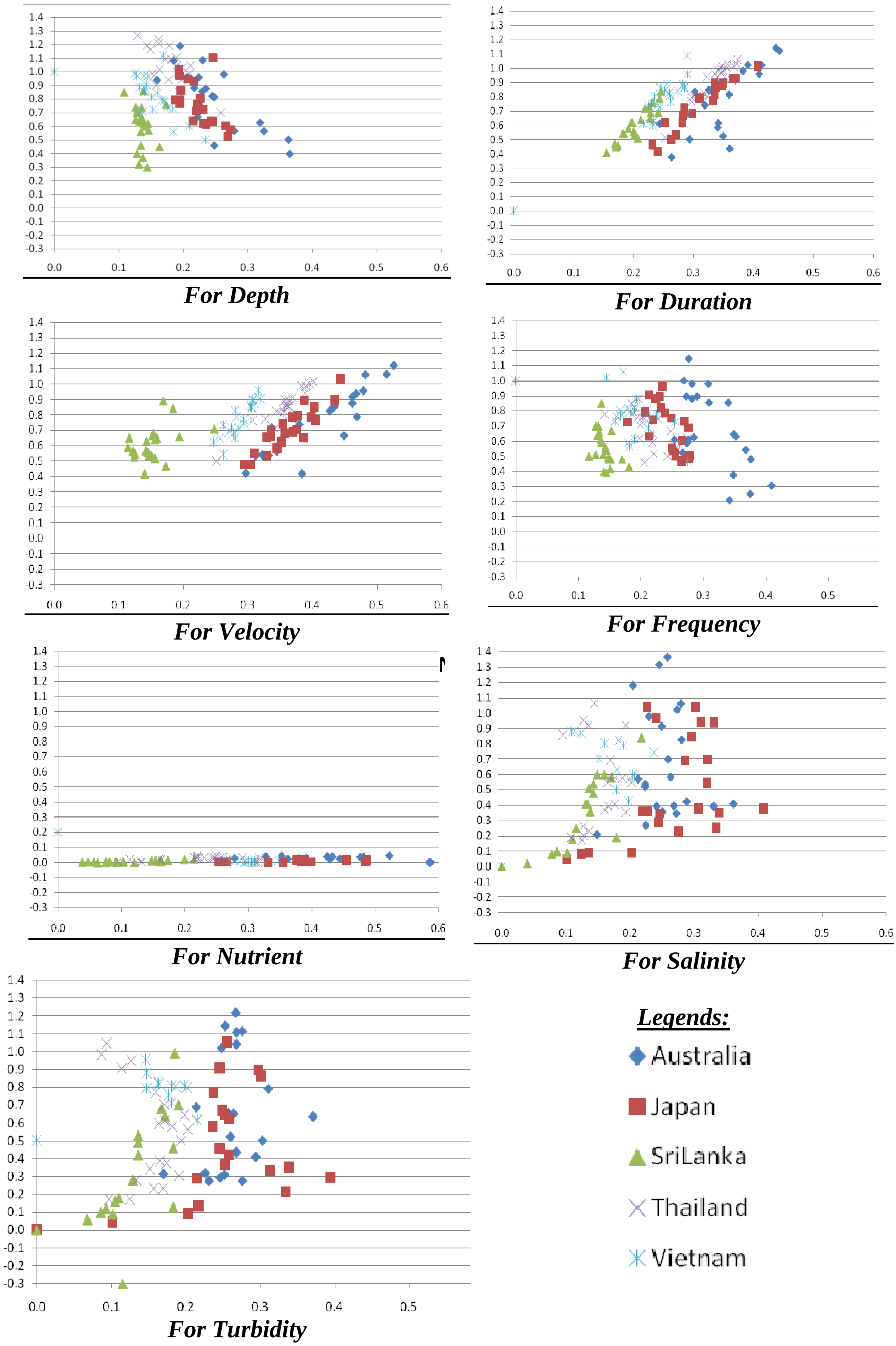


Figure 27: Scatter plots of Disparity (x-axis) vs. Sensitivity (y-axis) of all 22 issues for 4 inundation and 3 water quality parameters for five countries

Classification of relationships between impact ranking and key issues

Relationships between the impact ranking scores for the effects of high, medium and low magnitudes for all combinations of flood hazard parameters and key issues were grouped into the following four classes as explained in Dutta et al., 2010.

Class 1: High sensitivity and High Agreement (or low disparity)
Class 2: High sensitivity and Low Agreement (or high disparity)
Class 3: Low sensitivity and High Agreement (or low disparity)
Class 4: Low sensitivity and Low Agreement (or high disparity)

The key issues that show high sensitivity to increasing magnitude for a particular hazard parameter and for which there is high agreement among respondents (i.e., high correlation or narrow confidence interval for the slope CIs) were placed in Class 1. All the key issues in this class show a reasonably strong, monotonic relationship with increasing magnitude of the particular flood hazard parameters; and good agreement among stakeholder respondents about these relationships. Key issues in Class 2 appear to be sensitive to the increasing magnitude of the hazard parameters, but the opinions of different stakeholders about these relationships are varied. Class 3 includes key issues which stakeholders agree are not particularly affected by an increase in magnitude of the hazard parameters. The key issues in Class 4 also appear to be less sensitive to the hazard parameters, however, there are more widely varying perceptions among stakeholders about these relationships.

Table 21 shows the Class 1 issues for different inundation and water quality parameters for five countries. It shows that Depth is considered to be highly sensitive to most of the issues and stakeholders across all countries had high agreement. Australia and Japan had similar issues showing high sensitivity and agreement. Thailand and Vietnam shared more similarity in terms of issues identified. Vietnam showed highest number issues with high sensitivity and high agreement than other countries.

The results show that stakeholders do not prioritise issues and/or hazards for adaptation and mitigation measures similarly across all countries. It is therefore important to take into account the different priorities of stakeholders in different countries.

Pairwise correlations between sensitivities

In order to compare the impact assessments across the five countries, the product-moment correlations between the sensitivity scores across the 22 key issues for each pair of countries and for each of the 7 hazard parameters were calculated; refer Table 22. A high positive correlation indicates a broadly similar perception across two country panels of the relative rankings of key issues in terms of how dramatically they are impacted by changes in the level of the relevant hazard parameter. Thus, in terms of the impact of increased flood depth on the range of key issues, the relative rankings are fairly consistent across Australia, Japan and Thailand, but more disparate across Sri Lanka and Vietnam and each of those sites with the first three. It is acknowledged that these patterns may be influenced by the selections of the panels or by the protocols used to obtain their survey responses. Overall, however, it would appear that there are some considerable differences between the perceptions at the various country sites of which key issues are most sensitive to changes in levels of the various hazard parameters.

Table 21: Issues that showed high sensitivity with high agreements for flood inundation and water quality parameters for five countries

Issues	**Australia**	**Japan**	**Sri-Lanka**	**Thailand**	**Vietnam**
Drainage	Dep	Dep, Frq	Dep, Vel, Frq, Dur, Sal	Dep,Frq	Dep, Dur, Frq
Roads	Dep	Frq, Dep	Dep, Dur, Frq, Vel	Dep,Frq	Dep, Dur, Frq
Railways	Dep, Frq	Frq, Dep	Dur, Dep, Vel, Frq	Dep,Frq	Dep, Vel, Frq, Tur
Ports	Dep, Dur, Frq	Dep, Dur, Frq	Dep, Frq, Dur, Vel	Dep,Frq	Dep, Dur, Frq
Dykes	Dep, Frq	Dep, Frq	Vel, Dur	Dep,Dur, Frq	Dep, Dur, Frq
Coast	Dep, Dur, Frq	Dep, Frq	Dur	Dep,Dur, Frq	Dep, Dur, Vel, Frq
Landuse	Dep	Frq, Dep	Vel, Dep, Dur, Frq	Dep,Frq, Sal,Tur	Dep, Dur, Vel, Frq
Residential buildings	Dep, Frq, Sal	Dep, Frq	Frq, Dur, Dep, Vel	Dep, Frq	Dep, Dur, Frq
Non-residentia l buildings	Dep Frq, Sal	Dep, Frq, Dur	Dur, Dep, Vel, Frq	Dep, Frq	Dep, Dur, Frq
Potable Water	Sal, Tur, Dep, Dur, Frq	Sal, Turb, Dur, Dep, Frq	Vel, Dur	Sal, Tur, Dep, Frq	Dep, Dur, Vel, Frq, Sal, Tur
Water quality	Sal, Tur, Dep,	Tur, Sal, Frq, Dep	-	Tur, Dep, Sal, Frq	Dep, Dur, Vel, Frq, Sal, Tur
Erosion	Dep	Dep, Frq	Vel, Dur	Dep, Frq	Dep, Dur, Frq, Tur, Sal
Tourism	Frq, Dep, Tur, Sal	Frq, Dep, Tur	Vel	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur
Short term displacement	Dep, Frq, Sal	Dep, Frq	Frq, Dr, Dep, Vel	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Long term displacement	Frq, Dep, Sal, Tur	Frq, Dep	Vel, Dur, Frq, Dep	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Agriculture	Sal, Dep, Frq	Frq, Dep, Tur	Dur, Sal, Tur, Vel, Frq, Dep	Dep, Sal, Frq, Tur	Dep, Dur, Vel, Frq, Tur, Nut
Fisheries	Tur, Sal, Dur	Tur, Frq, Dep	Dep, Frq, Tur, Vel, Sal	Dep, Tur, Sal, Dur, Vel	Dep, Dur, Vel, Frq, Tur, Sal
Fish habitat	Tur, Sal	Dur, Dep, Frq	Dep, Vel, Dur	Tur, Dep, Sal, Frq	Dep, Dur, Vel, Frq, Tur, Sal
Wetland extent	Sal, Tur	Dep, Dur, Tur, Frq	Dep, Dur, Vel, Frq	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Flora *diversity*	Tur, Sal	Sal, Tur, Dep, Dur	Tur, Dep, Sal, Dur, Frq, Vel	Dep, Sal, Tur, Frq	Dep, Dur, Vel, Frq, Nut
Fauna *diversity*	Tur, Sal	Sal, Tur, Dep, Dur	Tur, Vel, Dep, Sal, Frq, Dur	Dep, Sal, Tur, Frq	Dep, Dur, Vel, Frq, Tur, Sal
Mangroves	Tur, Dep	Dep, Frq	Tur, Dur, Sal, Dep, Vel	Dep, Dur, Vel	Dep, Dur, Vel, Frq, Tur, Sal

Table 22: Pairwise correlations between sensitivities

Hazard parameters	Countries	Aust	Japan	Sri Lanka	Thailand	Vietnam
DEPTH	Aust		0.722	0.068	0.761	0.588
	Japan			0.288	0.740	0.545
	SriLanka				0.314	0.058
	Thailand					0.448
DURATION	Aust		0.732	0.609	0.670	0.434
	Japan			0.200	0.773	0.262
	SriLanka				0.409	0.103
	Thailand					0.224
VELOCITY	Aust		0.539	0.308	0.503	0.400
	Japan			0.600	0.353	0.133
	SriLanka				0.255	-0.058
	Thailand					0.238
FREQUENCY	Aust		0.793	0.296	0.558	0.053
	Japan			0.279	0.508	0.338
	SriLanka				0.377	0.374
	Thailand					0.223
NUTRIENTS	Aust		-0.096	-0.005	0.087	0.448
	Japan			0.027	-0.038	0.064
	SriLanka				0.283	-0.161
	Thailand					-0.636
SALINITY	Aust		0.916	0.428	0.936	0.702
	Japan			0.617	0.935	0.744
	SriLanka				0.449	0.308
	Thailand					0.781
TURBIDITY	Aust		0.939	0.464	0.915	0.635
	Japan			0.435	0.950	0.718
	SriLanka				0.386	-0.101
	Thailand					0.746

4.5 Application of the MCDM Tool in Australia, Bangladesh, Japan, Sri Lanka, Thailand and Vietnam

Figures 28 and 29 show weighted priority vectors across all the alternatives for comparison purpose. Figure 28 shows the preferences on alternative strategies for sustainable management in Australian context. A similar analysis is expected to perform across all collaborating countries using their own case study data in order to develop the consensus on the preferred strategy as appropriate. Figure 4 shows a comparison on the preferences of strategies across all six countries. As seen, it is clear that the most preferred solution in one country may not be the solution to others in terms of developing adaptive measure for sustainable future.

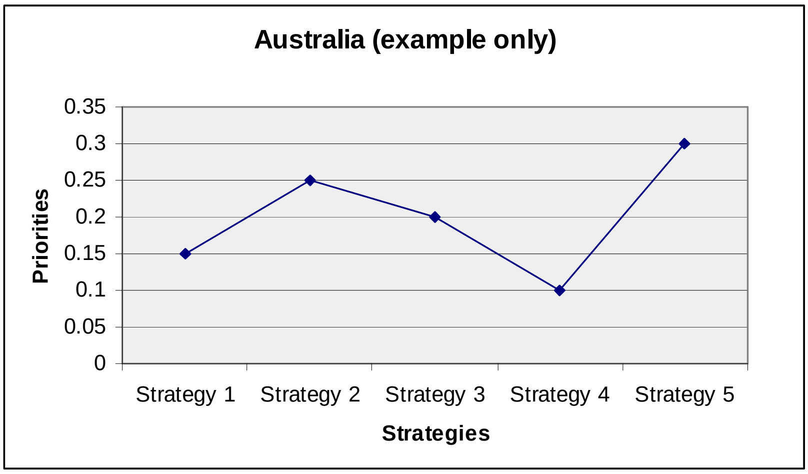


Figure 28: Percentage representation of overall priorities for three individual cases

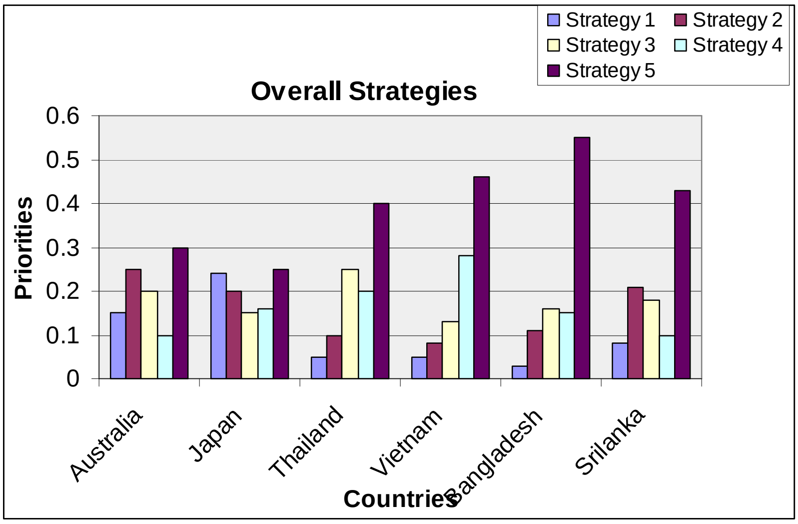


Figure 29: Percentage representation of overall priorities for optimum management strategy

5. Conclusions

An innovative integrated tool was development for accurately capturing changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing, for identifying sound metrics for assessment of impacts of these changes and for examining long-term adaptation and mitigation measures for sustainable management. In the development of the tool, a holistic approach was adopted with the emphasis on applying LCA principles to the coastal zone systems in cross-cutting issues to overcome the limitations of the existing fragmental approaches for evaluating more complex and interrelated biogeochemical and physical processes in coastal zones that include nutrient flux, salinity, floods, erosion and sedimentation and their impacts on society, economy and environment. The integrated tool included three major components: process-model, impact assessment tool and MCDM tool. Several pilot case studies were conducted in six selected case coastal regions in the six member countries of the project namely: Australia, Bangladesh, Japan, Sri Lanka, Thailand and Vietnam. The outcomes of the case studies were presented to broader audience from more than 15 countries in an international symposium that was held at Monash University, Australia during 12-13 April 2010 a part of the project. The key findings of the case studies have been presented in the proceedings of the symposium (Dutta and Wright, 2010) (Appendix XX).

A few key findings and outcomes from the some of the individual case study applications are highlighted below:

- The case The case study application of the salinity model in the Southwest coastal region of Bangladesh (Bhuiyan and Dutta, 2010) shows that there will be significant impacts on SLR on floods and river salinity in the region and the existing polders at some particular locations are not adequate to protect flood against 59 cm SLR. Breaching of polders at other locations can resulting in floods and salinity intrusion in adjacent areas.
- The case study application of the sediment and nutrient dynamics models the Latrobe basin of the Gippsland Lakes catchment (Kabir & Dutta, 2010; Alam & Dutta, 2010) show that sediment and nutrient dynamics in this river system will be significantly affected by the project climate changes. The projected increase in rainfall intensity in the basin will contribute to increase concentration of suspended sediments and the projected temperature rise will contribute to the deterioration of water quality with increased concentration of nutrients in river water.
- Through the case study application of the impact assessment tool in the Gippsland coastal zones (Dutta et al., 2010), the key issues of concern for this region for flood impacts were identified and a series of synthetic response functions were developed for some of these key issues for quantification of impacts of floods on these key issues in the region. The analysis also showed that some of the issues are considered not to be significantly affected by floods and thus may not require adaptation measures. The synthetic response functions as developed in this study can be used to quantify the likely impacts of flood hazards of various magnitudes and thus, allows natural resource managers and decision makers to better understand the risks associated with sea level rise and to prioritise adaptive management strategies for the region.
- The case study application of the impact assessment tool in five selected coastal zones in Australia, Japan, Sri Lanka, Thailand Vietnam (Wright et al. 2010) shows that stakeholders in different countries prioritise the flood impact issues differently, although there are similarities between priorities in Australia and Japan, and to a lesser extent Thailand. Differences in methodology may explain a very different response in Sri Lanka, but Vietnamese and SriLankan stakeholders responded differently in their priorities.
- The case study of the MCDM tool in the six case study areas (Doloi, 2010) highlights the different priorities of the stakeholders in adaptation measures and thus, the most preferred solution in one country may not be the solution to others in terms of developing adaptive measure for sustainable future.

6. Future Directions

Due to the limited financial support and difficulty in obtaining required data and information, some of the case study applications are still in progress. The project team will attempt to complete these on-going case studies in the coming year and publish the outcomes in peer-reviewed journal and conference proceedues.

The methodology and tool developed in this project has broad applicability in coastal zones. There is a scope to expand the case studies to other major coastal zones of the Asia-Pacific region.

One of the potential future scientific research is to expand the methodology to incorporate related issues such as groundwater. A PhD research is currently under way to incorporate groundwater salinity model in the integrated tool.

References

ADB, 2005. Southwest Area Integrated Water Resources Planning and Management Project in Bangladesh. Asian Development Bank.

Alam, M.J. and D. Dutta (2010). Quantification of Climate Change Impact on Nutrient Pollution: Application of a Dynamic Model for Latrobe River Basin in Australia, Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 12-13 April, 2010, Monash University, Australia, 33-42.

APN (2005). APN Strategic Plan (2005-2010), Asia-Pacific Network for Global Change Research, Kobe, Japan, 20p.

Barua, D. K., 1991. The coastline of Bangladesh – An Overview of Processes and Forms. In: Proceedings of the Seventh Symposium on Coastal and Ocean Management. ASCE, Long Beach, CA 8 – 12.

Belfiore, S. (2003). The growth of integrated coastal management and the role of indicators in indicators in integrated coastal management: introduction to the special issue. Ocean and Coastal Management 46, 225-234.

Berning, C., Viljoen, M.F., and Plessis, L.A. (2000). Loss functions for sugar-cane: Depth and Duration of Inundation as Determinants of Extent of Flood Damage, Water SA 26(4), 527-530.

Bhattarai, R. and D. Dutta (2005). Analysis of Soil Erosion and Sediment Yield using Empirical and Process Based Models, Proceedings of the MTERM International Conference, AIT, 215-226.

Bhuiyan, M. J. A. N., DUTTA, D., GUPTA, A. D. & BABEL, M. S., 2005. Flood Simulation and Its Socio-Economic Impact Analysis in Meghna Delta, Bangladesh Under Climate Change Conditions. International Symposium on Floods in Coastal Cities under Climate Change Conditions, June, 2005, Thailand.

Bhuiyan, M.J. and D. Dutta (2010). An Adaptation Strategy for Sea Level Rise Impact on Coastal Cities: A Case Study, South Western Coastal Region of Bangladesh, Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 12-13 April, 2010, Monash University, Australia, 303-313.

Brooke, C. and Hennessy, K., 2005. Climate change impacts in Gippsland, CSIRO Marine and Atmospheric Research.

Chapra, S. C., 1997. Surface-Water Quality Modelling. WCB McGraw Hill, USA.

Clark, J.R. (1992). Integrated Management of Coastal Zones. FAO, Rome, FAO Fisheries Technical Paper No. 327.

CSIRO and BoM, (2007). Climate change in Australia, Technical report, CSIRO and Bureau of Meteorology through the Australian climate change science program. Downloaded from www.climatechangeinaustralia.gov.au

Das and Lee, 1988;
Doloi, H. and Jaafari, A. (2002) “Towards a Dynamic Simulation Model for Strategic Decision Making in Life Cycle Project Management" Project Management Journal, Vol. 33 (4), December 2002, pp. 23-38.
Doloi, H (2010). Framework for Multicriteria Decision Modeling for Analysing Sustainable Management Strategy, Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 12-13 April, 2010, Monash University, Australia, 83-92.
Doloi, H. (2008). Application of AHP in improving construction productivity from a management perspective, Construction Management and Economics (in press).
Dougherty, TC and Hall, AW, 1995. Environmental impact assessment of irrigation and drainage projects. FAO Irrigation and drainage paper no 53. FAO, Rome. ISBN 92-5-103731-0. 53. 74pp.
Dutta, D., S. Herath and K. Musiake (2003). A Mathematical Model for Flood Loss Estimation, Journal of Hydrology, 277:24-49.
DPI 2009
Dutta, D., S. Herath and K. Musiake (2000). Flood Inundation Simulation in a River Basin Using a Physically Based Distributed Hydrologic Model, Hydrological Processes, 14(3):497-520
Dutta, D., S. Herath and K. Musiake (2006). An Application of a Flood Risk Analysis System for Impact Analysis of a Flood Control Plan in a River Basin, Hydrological Processes, 20(6):1365–1384
Dutta, D., M.S. Babel and A. Das Gupta (2005). An Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas, Final Report for APN CAPaBLE Project: 2004-CB01NSY-Dutta, Asian Institute of Technology, ISBN 974-93908-0-6, 205 pages.
Dutta, D. (ed) (2007). Proceedings of the Planning Workshop of the APN Project on Climate Perturbation and Coastal Zone Systems In Asia Pacific Region, Bangkok, Thailand, 27-28 September 2007, A Report of the Sponsored Research Project, School of Applied Sciences and Engineering, Monash University, 51 pages.
Dutta, D., J. Alam, K. Umeda, M. Hayashi and S. Hironaka (2007). A two dimensional hydrodynamic model for flood inundation simulation: a case study in the Lower Mekong River basin, Hydrological Processes, 21:1223-1237.
Dutta, D., W. Wright and P. Rayment (2010). Use of Synthetic Impact Response Functions for the analysis of vulnerability to flood damage in Gippsland Coastal Zones, Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 12-13 April, 2010, Monash University, Australia, 419-432.
Dutta, D. and J.A.N. Bhuiyan (2007). Flood Characteristics under Changing Climatic Conditions in Meghna Delta, Bangladesh, Proceedings of the 16th IASTED International Conference on Applied Simulation and Modelling, Spain, 29 – 31 August, pp.162-167.
Dutta, D. and W. Wright (ed). (2010). Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, Proceedings of the International Symposium, Organized School of Applied Sciences and Engineering, Monash University, Published by Monash University, ISBN 978-0-7326-4011-8, 474 pages
Dutta, D. and K. Nakayama (2009). Effects of Spatial Grid Resolution on River Flow and Surface Inundation Simulation by Physically Based Distributed Modeling Approach, Hydrological Processes, 23, 534-545.
Finkele, K., Mills, G.A., Beard, G. & Jones, D.A., 2006. National gridded drought factors and comparison of two soil moisture deficit formulations used in prediction of forest fire danger index in Australia, Aust.Met.Mag.55:183-197.
Fisher, P., Abrahart, R. J. & Herbinger, W., 1979. The sensitivity of two distributed non-point source pollution models to the spatial arrangement of the landscape. Hydrological Processes 11: 241-252.
Garnier, J., J. Nemery, G. Billen and S. Thery (2005). Nutrient dynamics and control of eutrophication in the Marne River system, Journal of Hydrology 304, 397-412.
Gates, T. K., ASCE, M., Burkhalter, J. P., ASCE, M., Labadie, J. W., ASCE, M., Valliant, J. C. and Broner, I., 2002. Monitoring and Modeling Flow and Salt Transport in a

Salinity-Threatened Irrigated Valley. Journal of Irrigation and Drainage Engineering, 128, 87-99.
GCB (2008). Climate Change, Sea Level Rise and Coastal Subsidence along the Gippsland Coast: Implications for geomorphological features, natural values and physical assets, Phase 2 - Gippsland Climate Change Study, Gippsland Coastal Board, Final Report, May 2008
Gordon, D.C. Jr., P.R. Boudreau , K.H. Mann, J.-E. Ong, W.L. Silvert, S.V. Smith, G. Wattayakorn, F. Wulff, and T. Yanagi. (1996). LOICZ Biogeochemical Modelling Guidelines, LOICZ Reports & Studies No. 5. Second Edition, vi +96 pp. LOICZ, Texel, The Netherlands.
Govers G., 1990. Empirical relationships on the transporting capacity of overland flow. International Association of Hydrological Sciences, 189, pp. 45-63.
Henderson-Sellars, B., Young, P. C., and Ribeiro da Costa, J., 1990. Water quality models: rivers and reservoirs, in Proc. 1988 Int. Symp. On Water Quality Modelling of Agricultural Non-Point Sources; United States Dept of Agriculture, Agricultural Research Service; 1990; Publication No. ARS-81, 381-420.
Herath, S. and U. Ratnayake (2004) “Monitoring Rainfall Trends to Predict Adverse Impacts – a Case Study from Sri Lanka (1964-1993)”, Journal of Global Environmental Change, Vol. 14, Supplement 1, pp 71 -79
Hong, G.H., H.H. Kremer, J. Pacyna, Chen-Tung Arthur Chen, H. Behrendt, W. Salomons and J.I. Marshall Crossland (2002). LOICZ Global Assessment and Synthesis of River Catchment-Coastal Sea Interaction and Human Dimensions. East Asia Basins, LOICZ Reports & Studies No. 26, ii + 262 pages, LOICZ IPO, Texel, The Netherlands
IPCC CZMS (1992). A common methodology for assessing vulnerability to sea level rise, 2nd revision. In: Global Climate Change and the Rising Challenge of the Sea. Report of the Coastal Zone Management Subgroup, Response Strategies Working Group of the Intergovernmental Panel on Climate Change, Ministry of Transport, Public Works and Water Management, The Hague, Appendix C.
IPCC (2001). Climate Change 2001: The Scientific Basis. Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Van der Linden, P.J., and Xioasu, D. (eds.), Cambridge and New York: Cambridge University Press. 881 pp.
IPCC, 2007. Climate Change and Biodiversity, Technical report 4, Inter-governmental panel on climate change (IPCC), Geneva.
Jones R. and Webb, L., 2008. Sectoral and regional vulnerabilities to climate change in Victoria, CSIRO Marine and Atmospheric Research, Aspendale
Kang, J.L., Su, M.D. and Chang, L.F. (2005). Loss Functions and Framework for Regional Flood Damage Estimation in Residential Area, Journal of Marine Science and Technology, 13(3), 193-199.
Krzysztofowicz, R., Davis, D.R. (1983). Category-unit loss functions for flood forecast–response system evaluation. Water Resources Research 19 (3), 1476–1480.
Kabir, M.A. and D. Dutta (2010). Analyzing Impacts of Climate Change on Sediment Dynamics in River Basins using a Process-Based Distributed Modeling Approach, Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 12-13 April, 2010, Monash University, Australia, 19-31.
Krzysztofowicz and Davis, 1983;
Leon, L.F., Soulis, E.D., Kouwen, N. and Farquhar, G. J., 2001. Nonpoint source pollution: A distributed water quality modelling approach, Water Research 35 (4): 997-1007.
Manivong, K. Jaafari, A., Gunaratnam, D., and Doloi, H. (2004). Architecture of an Intelligent Project Management Information System for Optimistic Capital Projects, Proceedings of the World IT Conference for Design and Construction, INCITE 2004, Langkawi, Malaysia, 18-21 Feb., pp 515-522.
Mitchell, W., Chittleborough, J., Ronai, B., and Lennon, G.W. (2000). Sea level rise in Australia and the Pacific, In: The South Pacific Sea Level and Climate Change Newsletter, 5(1), January 2000.
Morgan R.P.C., Quinton J.N., Smith R.E., Govers G., Poesen W.A., Auerswald K., Chisci G., Torri D., and Styczen M.E., 1998. The European Soil Erosion Model (EU-ROSEM): A

dynamic approach for predicting sediment transport from fields and small catchments. Earth Surf. Processes Landforms. 23, pp. 527-544.

Nakayama, K., D. Dutta, G. Tanaka and T. Okada (2004). Integration of Hydrological Model and Estuary Model, Journal of Japan Society of Hydrology and Water Resources, 18(4), 390-400.

Nakayama, K. (2005). Modeling the effect of stratification on sediment deposition, River, Estuary and Coastal Morphodynamics, Vol. 4, pp.1027-1034, 2005.

Nakayama K, K. Onishi, Y. Sugawara (2010). Impact of Sea Level Rise On Inundation in the Kushiro Wetland, Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 12-13 April, 2010, Monash University, Australia, pp. 55-60.

Neumann, J.E. and N.D. Livesay (2001). Coastal structures, dynamic economic modeling. In: Mendelsohn, R. (ed.), Global warming and the American economy , a regional assessment of climate change impacts. Cheltenham, U.K.: Edward Elgar, pp. 132-148.

Orlob, G. T. (ed.), 1983. Mathematical Modelling of Water Quality: Streams, Lakes and Reservoirs. J. Wiley, Chichester.

Post, J. C and C. G Lundin (1996), Guidelines to Integrated Coastal Zone Management, World Bank, Washington DC.

Potter N.J., Zhang L., Milly P.C.D., McMahon T.A., and Jakeman A.J., 2005. Effects of rainfall seasonality and soil moisture capacity on mean annual water balance for Australian catchments. Water Resources Research, 41 (6).

Ratnayake, U. R. and Herath, G.B.B. (2004) “Recent Changes in Water Cycle and its Effect on Natural disasters and Eco Systems of Sri Lanka”, Proceedings, “Preparatory workshop on Sri Lanka national water development report”, for UN-WWAP, 29-30 October 2004, Wattala, Sri Lanka.

Saaty, T.L. (1980). The Analytical Hierarchy Process, McGraw-Hill, New York. 1980.

Sabhasri, S. and K. Suwarnarat, 1996: Impact of sea level rise on flood control in Bangkok and vicinity. In: Sea-Level Rise and Coastal Subsidence: Causes, Consequences and Strategies [Milliman, J.D. and B.U. Haq (eds.)]. Kluwer Academic Publishers, Dordrecht, Netherlands, 343-355 pp.

Smith, D.I. (1994). Flood damage estimation—a review of urban stage-damage curves and loss functions. Water SA 20, 231–238.

Smith R.E., Goodrich D., and Quinton J.N., 1995. Dynamic distributed simulation of watershed erosion: the KINEROS2 and EUROSEM models. Journal Soil and Water Conservation, 50, pp. 517-520.

Smith, D.I. and M. Greenway (1988). The computer assessment of urban flood damage:’ ANUFLOOD’, Technical Report, Desktop Planning, Melbourne, Hargreen, Australia.

Steffen, W., 2009. Climate Change 2009 Faster Change & More Serious Risk, Department of Climate Change, Australian Government, Canberra

Thammasittirong (1999).Operational Flood Forecasting for Chao Phraya River Basin, Thesis WM-99-23, AIT, Thailand.

Thom, B.G. (2002) CZM in NSW: The Good, the Bad and the Ugly. In: Coast to Coast 2002, proceedings, pp. 468-470.

Titus, J.G., 1998. Rising seas, coastal erosion, and the takings clause: how to save wetlands and beaches without hurting property owners. Maryland Law Review 57, 1279-1399.

Torri D., Sfalaga M., and Del Sette M., 1987. Splash detachment: runoff depth and soil cohesion. Catena, 14, pp. 149-155.

Viljoen, M.F., Plessis, L.A. and Booysen, H.J. (2001). Extending Flood Damage Assessment Methodology to Include Sociological and Environmental Dimensions, Water SA 27(4), 517-521.

Walsh, K. (2004). Climate Change and Coastal Response, A theme report from the Coast to Coast 2002 National Conference, Gold Coast, November 2002, Melbourne University, Australia, 34p.

Whitehead, P.G., Wilson, E.J. and Butterfield, D., 1998a. A semi-distributed integrated nitrogen model for multiple source assessment in catchment. Part I. Model structure and process equations, the Science of the Total Environment 210/211:547-558.

Whitehead, P.G., Wilson, E.J., Butterfield, D. and Seed, K., 1998b. A Semi-Distributed Integrated Flow and Nitrogen Model for Multiple Source Assessment in Catchments -(Inca): Part II- Application to Large River Basins in South Wales and Eastern England, The Science of the Total Environment, 210/211: 559-83.

Williams, J. R., 1975. Sediment-yield prediction with Universal Equation using runoff energy factor. Present and Prospective Technology for Predicting Sediment Yields and Sources, ARS-S-40, US Department of Agriculture, Agricultural Research Service:244-252.

Williams, J. R. and Berndt, H.D., 1977. Sediment yield prediction based on watershed hydrology, Trans. Am. Soc. Agric. Eng. 20: 1100-1104.

Wright, W., D. Dutta and P. Rayment (2010). Flood Vulnerability Analysis in Coastal Zones: A Comparative Analysis Across Five Asia-Pacific Countries, Proceedings of the International Symposium on International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 12-13 April, 2010, Monash University, Australia, 433-443.

Young, P.C., and Wallis, S.G., 1992. Solute transport and dispersion in channels, forthcoming in: K.J. Beven and M.J. Kirby (eds), Channel Networks, J. Wiley, Chichester.

Appendix A:

Project Workshops/Symposia: Agenda, Program and List of Participants

- Planning Workshop of the APN Project ARCP2007-14NMY, 27-28 September 2007, Bangkok, Thailand
- Brainstorming Workshop of the APN Project ARCP2007-14NMY, 16-17 June 2008, Hanoi, Vietnam
- International Symposium on Coastal Zones and Climate Change: Assessing the Impact and Developing Adaptation Strategies (CZCC2010), 11 – 13 April, 2010, Monash University, Victoria, Australia

Planning Workshop of the APN Project ARCP2007-14NMY

27-28 September 2007

Venue:

Rama Gardens Hotel
9/9 Vibhavadi Rangsit Road, Laksi, Bangkok 10210 Thailand
Tel: (66 2) 561-0022, Fax: (66 2) 561-1025, 561-3416
http://www.ramagardenshotel.com/RamaGardens/

Convener: Dr. Dushmanta Dutta, Monash University
Project Leader, ARCP2007-14NMY

Local Organizer: Dr. Dhirendra Thakur, Asian Institute of Technology
Project Collaborator from Thailand

Objectives of the Workshop:

The main agenda of the planning workshop is development of the integrated framework for tool development and applications. The workshop will be a platform for all main collaborators to present their ideas and outcomes of the PRG meetings and detailed information on the feasible study areas identified. All the points raised by the collaborators will be thoroughly discussed and deliberated. Outcomes of the discussion would lead to formulation of an integrated framework for the development and application of the holistic tool. The planning workshop will play a crucial in consensus building and incorporating stakeholders' inputs in the project activities.

Agenda

Day 0 (Wednesday, 26 September)

- Arrival of the participants in Bangkok

Day 1 (Thursday, 27 September)

9:00-11:00: Introductory Session (Facilitator: W. Wright)

- Welcome and overview of project objectives and planned activities (D. Dutta)
- Presentation by all participants on individual perspectives on the project

Coffee break (11:00-11:30)

11:30-12:30: Case Study areas and past related studies (Facilitator: D. Dutta)

- Australia (S. Adeloju)
- Bangladesh (M. Rahman)
- Japan (K. Nakayama)
- Sri Lanka (U. Ratnayake)
- Thailand (D. Thakur/D. Dutta)
- Vietnam (V. T. Ca)

(Presentation on the Case study areas should include at least: a brief overview of the area including socio-economic and environmental characteristics, relevance/importance to the project, past related studies and outcomes)

Lunch Break (12:30-13:30)

13:30-15:30: Stakeholders response (Facilitator: H. Doloi)

- Outcomes of PRG Meetings in:
    - Australia (W. Wright)
    - Bangladesh (M. Rahman)
    - Japan (K. Nakayama)
    - Sri Lanka (U. Ratnayake)
    - Thailand (D. Thakur)
    - Vietnam (V. T. Ca)

16:00: Departure to Bangkok for dinner

- o Boat trip on Chao Phraya (evening cruise)

Day 2 (Friday, 28 September)

9:00-11:00: Brainstorming Session (Facilitator: S. Adeloju)

- o Commonality of stakeholders views' and case study areas in different countries
- o On project framework (D. Dutta)
- o Modeling components (D. Dutta)
- o Implementation strategy and timeline (H. Doloi)

Coffee break (11:00-11:30)

11:30-12:30: Planning of data collection activities (Facilitator: S. Ratnayake)

- o Data for physical modelling (D. Dutta)
- o Data for impact assessment tool (W. Wright)
- o Data for MCDM analysis (H. Doloi)

Lunch Break (12:30-13:30)

13:30-15:00: Planning of development of integrated assessment tools (Facilitator: K. Nakayama)

Coffee break (15:00-15:30)

15:30-16:30: Final Reporting of the workshop

- o brief summary by the facilitator of each session

List of Participants

No.	Full Name	Organization (Country)	APN Project responsibility
1	Dr. Dushmanta Dutta	Monash University (Australia)	Project Leader
2	Prof. Samuel Adeloju	Monash University (Australia)	Chief Investigator
3	Dr. Wendy Wright	Monash University (Australia)	Chief Investigator
4	Dr. Hemanta Doloi	University of Melbourne (Australia)	Chief Investigator
5	Prof. Mafizur Rahman	Bangladesh University of Engineering and Technology (Bangladesh)	Collaborator from Bangladesh
6	Prof. Keisuke Nakayama	Kitami Institute of Technology (Japan)	Collaborator from Japan
7	Dr. Uidtha Ratnayake	Peradeniya University (Sri Lanka)	Collaborator from Sri Lanka
8	Dr. Vu Thanh Ca	Institute of Meteorology and Hydrology (Vietnam)	Representing Dr. T. Thuc, Collaborator from Vietnam
9	Dr. Dhirendra Thakur	Asian Institute of Technology (Thailand)	Collaborator from Thailand

Brainstorming Workshop of the APN Project ARCP2007-14NMY

16-17 June 2008

Venue:
Hanoi Heritage Hotel

625 – Lathanh, Badinh, Hanoi
Tel: 844 – 8344727 Fax: 844 – 8343882
Email: hanostour@hn.vnn.vn
Website: http://www.hotels-in-vietnam.com/hotels/hanoi/heritage_hotel.html

Convener: Dr. Dushmanta Dutta,
School of Applied Sciences and Engineering, Monash University
Project Leader, ARCP2007-14NMY

Local Organizers: Dr. Vu Thanh Ca and Dr. Tran Thuc,
Project Collaborators from Vietnam
Vietnam Institute of Meteorology, Hydrology and Environment
5/62 Nguyen Chi Thanh, Hanoi, Vietnam
Tel: (84-4) 7730409

Contact for Local info: Miss Nguyen Thanh Tam
Vietnam Institute of Meteorology, Hydrology and Environment
5/62 Nguyen Chi Thanh Street, Dong Da, Hanoi
Tel: 04 7733090, ext 414
Mobile: 0989 386 836

Objectives of the Workshop:

The main agenda of the brainstorming workshop is to review the progress of the project. During the two days of the workshop, our targets would be to achieve the following objectives:

1) Review the progress of the three main activities of Year 1 in each country
   a. data collection and collation,
   b. flood modelling
   c. questionnaire survey for developing impact assessment indicators
2) Develop a detailed plan for Year 2 activities
3) Prepare a draft progress report to submit to APN as an outcome of Year 1 and for obtaining fund for Year 2

The program of the workshop has been prepared to cover and achieve the objectives.

Program

Day 0 (Sunday, 15 June)

- Arrival of the participants in Hanoi

Day 1 (Monday, 16 June)

9:00-10:30: Session 1
Overview of progress project activities in each country (Facilitator: H. Doloi)

- Australia (D. Dutta)
- Bangladesh (M. Rahman)
- Japan (K. Nakayama)
- Sri Lanka (U. Ratnayake)
- Thailand (D. Thakur)
- Vietnam (V.T. Ca)

Coffee break (10:30-11:00)

11:00-12:30: Session 2
Presentation on outcomes of flood modelling in case study areas (Facilitator: V. T. Ca)

- Australia (D. Dutta)
- Bangladesh (M. Rahman)
- Japan (K. Nakayama)
- Sri Lanka (U. Ratnayake)
- Thailand (D. Thakur)
- Vietnam (V.T. Ca)

Lunch Break (12:30-13:30)

13:30-15:30: Session 3
Presentation on outcomes of the questionnaire survey (Facilitator: W. Wright)

- MCDM Questionnaire survey outcomes (H. Doloi)

- TBL Questionnaire survey outcomes (moderated by W. Wright)
  - Australia (W. Wright)
  - Bangladesh (M. Rahman)
  - Japan (K. Nakayama)
  - Sri Lanka (U. Ratnayake)
  - Thailand (D. Thakur)
  - Vietnam (V.T. Ca)

Note for the session 3 presentation:
H. Doloi will present a 10minute summary of the development of the MDCM component of the project. After that, Wendy Wright would moderate discussions on TBL questionnaire survey outcomes. Each country collaborator would be asked to give a brief overview of the outcomes of the "Questionnaire for Development of Response Functions for TBL impact analysis". Each summary should include an overview of completed questionnaires. After the summary, Wendy Wright would present an overview of the common method developed for statistical analysing of the outcomes of the survey for developing response functions. This session would then take the form of a hands-on session, where every country collaborator would utilize the statistical method to analyse their datasets to procedure preliminary outputs for comparative analysis.

Coffee break (15:30-16:00)

16:00-17:00: Session 4
Deliberation on case study outcomes and way forward (Facilitator: S. Adeloju)

(Moved to Day 2 after the first session)

17:30
Departure for dinner (place to be decided soon)

Day 2 (Tuesday, 17 June)

9:00-10:30: Session 5
Updates on water quality data status and trend analysis (Facilitator: D. Thakur)
- Australia (S. Adeloju)
- Bangladesh (M. Rahman)
- Japan (K. Nakayama)
- Sri Lanka (U. Ratnayake)
- Thailand (D. Thakur)
- Vietnam (V.T. Ca)

Note for the session 4 presentation:
In this session, the presenters are requested to use the following format of presentations:
- status of collected/available data (including their temporal resolution and spatial distribution) on water quality parameters identified in Bangkok Workshop (N, NO_2, NO_3, TP, PO4, Salinity, Turbidity (SS)) for the chosen case study area in each country
- water quality trends in past several years (longer trend would give us better understanding of variation of water quality)

Coffee break (11:00-11:30)

11:00-12:30: Session 6
Plan for water quality modelling and other activities (Facilitator: N. Keisuke)

Lunch Break (12:30-13:30)

13:30-16:00: Session 7
Planning for Year 2 and Draft reports for APN (Facilitator: D. Dutta)

Coffee break (16:00-16:30)

17:30
Departure for Halong Bay (further information will be provided by Ca related to this trip).

List of Participants

No.	Full Name	Organization (Country)	APN Project responsibility
1	Dr. Dushmanta Dutta	Monash University (Australia)	Project Leader
2	Prof. Samuel Adeloju	Monash University (Australia)	Chief Investigator
3	Dr. Wendy Wright	Monash University (Australia)	Chief Investigator
4	Dr. Hemanta Doloi	University of Melbourne (Australia)	Chief Investigator
5	Prof. Mafizur Rahman	Bangladesh University of Engineering and Technology (Bangladesh)	Collaborator from Bangladesh
6	Prof. Keisuke Nakayama	Kitami Institute of Technology (Japan)	Collaborator from Japan
7	Dr. Uidtha Ratnayake	Peradeniya University (Sri Lanka)	Collaborator from Sri Lanka
8	Dr. Dhirendra Thakur	Asian Institute of Technology (Thailand)	Collaborator from Thailand
9	Dr. Tran Thuc	Institute of Meteorology and Hydrology (Vietnam)	Collaborator from Vietnam
10	Dr. Vu Thanh Ca	Institute of Meteorology and Hydrology (Vietnam)	Collaborator from Vietnam

International Symposium on Coastal Zones and Climate Change: Assessing the Impact and Developing Adaptation Strategies (CZCC2010)
11 – 13 April, 2010
Monash University Gippsland Campus

Program

Sunday 11 April 2010		
6.00pm – 8.00pm	**Symposium Reception - Comfort Inn Cedar Lodge, Morwell**	
Monday 12 April 2010		
8:00am – 4.00pm	**Registration**	
9:00am – 9:30am	**Symposium Opening - Auditorium** • Welcome to Country: **Mr Wayne Thorpe** • Opening: **Professor Helen Bartlett, Pro Vice Chancellor and President, Monash University Gippsland** • Symposium Objectives: **Dr Dushmanta Dutta, Chair, Organizing Committee** **MC: Dr Wendy Wright, Co-Chair, Organizing Committee**	
9:30am - 10:30am	**Plenary Session: Keynote Presentation I** Auditorium **Dr Kathleen L. McInnes, CSIRO** Global Warming, Sea Level Rise and Impacts on Coastal Zones in Australia **Chair: Dr Wendy Wright**	
10.30am – 11.00 am	Group Photo Morning Tea – Auditorium Foyer	
Session 1 11.00am – 1pm	**Session 1a: Adaptation strategies & policies** **Room A** **Chair: Professor Sam Adeloju**	**Session 1b: Assessing vulnerability & impacts** **Room B** **Chair: Dr Wendy Wright**
	Md. Mafizur Rahman Cost Effective Adaptation strategy for the Disaster prone areas of coastal areas of Bangladesh **Fernando Santos** Resilience Planning For Coastal Zone Management **Thanh Ca Vu** Risk based approach to adaptation to climate change and sea level rise – a pilot study at a coastal site in Vietnam **Md. Bhuiyan** Adaptation Strategies For Sea Level Rise Impact On Coastal Cities: A Case Study, South Western Coastal Region Of Bangladesh **Momin Mozibul Haque Shamaji** Adaptation Strategies and Policies of LGED of Bangladesh in the coastal areas **Uttam C. Sharma** Impact of Climate Change in Coastal Zones of India and Adaptation Strategies and Policies for Environment and Food Security	**Md. Sazedul karim Chowdhury** Climate Change Impacts in Coastal Zones: context Bangladesh **Md. Abdul Quadir** Effect of climate change in coastal belt of Bangladesh **Gemunu Herath** Issues of Groundwater Management in Asia Region **Phil Rayment** Synthetic Impact Response Functions for Vulnerability Analysis and Adaptation Measures in Coastal Zones under Climate Change Conditions: A comparative analysis across five Asia-Pacific countries

Monday 12 April 2010 (cont'd)	
1.00pm – 2.00pm	Lunch - Auditorium Foyer
Session 2 2.00pm – 3.40pm	**Session 2a: Adaptation strategies & policies <u>Room A</u>** **Chair: Dr Phil Rayment**
	Olivia P Montecillo Climate Change Adaptation Strategies Of Selected Coastal Communities In The Philippines **Geoff Taylor** Loch Sport - Planning for climate change **Satya Priya** Regional Climate Change Adaptation Platform for Asia **Geoff Wescott** Implementing Climate Change Policies consistent with Integrated Coastal Zone Management: a case study of Victoria, Australia. **Upali Imbulana** Meeting the challenges of climate change impacts on the coastal zone of Sri Lanka
3.40pm – 4.00pm	Afternoon tea - Auditorium Foyer
Session 3 4.00pm – 5.40pm	**Session 3: Monitoring & Modelling <u>Room A</u>** **Chair: Dr Satya Priya**
	Dushmanta Dutta An Integrated Modelling approach for Assessment of Impacts of Climatic Changes on Coastal Zone Systems **Uditha Ratnayake** Coupling Rainfall Downscaling and Flood Modeling for reliable flood and damage forecasting **Sanit Wongsa** Effect of Sea Water Level Change on the Management in the Lower Thachin River, Thailand **Keisuke Nakayama** Impact of sea level rise on inundation in Kushiro Wetland **Md. Jahangir Alam** Quantification of Climate Change Impact on Nutrient Pollution: Application of a Dynamic Model in Latrobe River Basin, Australia
6.00pm-8.00pm	**Traditional Australian BBQ Dinner – "Fishbowl"/Bistro Area**

<table>
<tr><th colspan="3">Tuesday 13 April 2010</th></tr>
<tr><td>8:00am – 4.00pm</td><td colspan="2">Registration</td></tr>
<tr><td>9:00am - 10:00am</td><td colspan="2">Plenary Session: Keynote Presentation II <u>Auditorium</u>
Mr Duncan Malcolm, Victorian Environmental Assessment Council
Climate Change – The Need for Adaptation on the Gippsland Coast
Chair: Dr Dushmanta Dutta</td></tr>
<tr><td>10.00am – 10.30am</td><td colspan="2">Morning Tea – Auditorium Foyer</td></tr>
<tr><td rowspan="2">Session 4
10.30am – 12.50pm</td><td>Session 4a: Assessing vulnerability & impacts <u>Room A</u>

Chair: Assoc. Professor Wescott</td><td>Session 4b: APN Special Session <u>Room B</u>

Chair: Dr Dushmanta Dutta
Recorder: Ms Charlotte Fisher</td></tr>
<tr><td>Hidayat Rahman
Enhancing coastal resilience in Asia against climate change: Challenges and Measures

Nick Wynn
The Future Coasts Program: Preparing Victorian Coastal Communities for the Effects of Climate Change

Claire Kain
Climate change and management of coastal lagoons in the Westland Region, New Zealand

Hiroshi Miyake
Kushiro Wetland Restoration Project

Luciano Absalonsen
Efficiency of beach nourishment projects in preventing erosion on the east and west coasts of Florida

Md Aynul Kabir
Analyzing Impacts of Climate Change on Sediment Dynamics in River Basins using a Process-based Distributed Modeling Approach</td><td>Discussion session only – for attendance by APN project participants</td></tr>
<tr><td>12.50pm – 2.10pm</td><td colspan="2">Lunch– Auditorium Foyer</td></tr>
<tr><td rowspan="2">Session 5
2.10 pm – 3.30pm</td><td colspan="2">Session 5: Monitoring & Modelling <u>Auditorium</u>
Chair: Dr Uditha Ratnayake</td></tr>
<tr><td colspan="2">Joseph Daniel
Impacts of sea level rise and climate change on waste water reticulation systems in the coastal regions of Gippsland, Victoria

Hemanta Doloi
Framework For Multicriteria Decision Modeling For Analysing Sustainable Management Strategy

Toshihito Toyabe
Monitoring of long-term trends of winter weather in Hokkaido

Rhys Collins
Estuary management and climate change</td></tr>
</table>

Tuesday 13 April 2010 (cont'd)	
3.30pm – 4.00pm	Afternoon tea– Auditorium Foyer
Session 6 4.00pm – 5.40pm	**Session 6: Stakeholders and Community engagement Auditorium** **Chair: Mr Duncan Malcolm**
	Dhirendra Prasad Thakur Climate Change Impacts And Community Level Adaptations: A Case Study On Marine Shrimp Farming In Thailand **Wendy Wright** Use of Synthetic Impact Response Functions for the analysis of vulnerability to flood damage in Gippsland coastal Zones **Md. Shibly Sadik** Community engagement in analyzing their livelihood resilience to climate change induced salinity intrusion in sundarbans mangrove forest **Neil Lazarow** Barriers and Bridges to the Effective Engagement by Local Government of Key Stakeholders in Coastal Climate Change Policy and Plans
6.00pm-8.00pm	**Symposium Closing and Dinner – "Fishbowl"/Bistro Area**

Agenda of the APN Special Session

Date: Tuesday 13 April 2010
Time: 10.30am – 12.50pm
Venue: Room B (of Monash University Gippsland Auditorium)
Chair: Dr D. Dutta
Recorder: Ms Charlotte Fisher

Objective:
This session will be attended by the members of the APN project only to discuss and update the progress of the APN project activities so far and the plan for the remaining activities. This session is organized as an informal meeting (without any formal presentation) as the main symposium program includes the formal presentations from the project members and their colleagues. Please prepare a few dot points for this session with the reference to the formal presentations at the Symposium (made by your or your colleagues).

Agenda (draft):

1. Overall progress of the APN project: D. Dutta
2. Report on Day 1 of the Symposium (by assigned reporters)
3. Update on country case studies (including modelling and TBL analysis):
    a. Australia: D. Dutta
    b. Bangaldesh: M. Rahman
    c. Japan: K. Nakayama
    d. Thailand: D. Thakur
    e. Sri Lanka: U. Ratnayake
    f. Vietnam: VT Ca
4. Update on MCDM system: H. Doloi
5. What is next?: D. Dutta
6. Final reporting to APN: D. Dutta

List of Symposium Participants

No.	Title	First Name	Last Name	Organisation
1	Mr.	Luciano	Absalonsen	Department of Coastal and Oceanographic Engineering - University of Florida
2	Prof.	Sam	Adeloju	Monash Uiversity
3	Mr.	Md. Jahangir	Alam	Monash University
4	Mr.	Md.	Bhuiyan	Monash University
5	Ms.	Robin	Britton	Resource Management Planner
6	Mrs.	Tania	Brooker	Department of Sustainability & Environment
7	Mr.	Md.Sazedul Karim	Chowdhury	Bangladesh Water Development Board
8	Mr.	Michael	Coldham	
9	Mr.	Sule	Daniel	Kogi State Government
10	Mr.	Joseph	Daniel	Monash University
11		Hemanta	Doloi	The University of Melbourne
12	Mr.	Adam	Dunn	West Gippsland Catchment Management Authority
13	Dr.	Dushmanta	Dutta	Monash University
14	Mr.	Alex	Edwards	Department of Sustainability and Environment
15	Ms.	Charlotte	Fisher	
16	Dr.	Gemunu	Herath	University of Peradeniya
17	Mr	Chow	Hirunteeyakul	Monash University
18	Ms.	Julie	Hocking	
19	Mr.	Tom	Hurst	Melbourne Water
20	Mr.	Upali	Imbulana	Ministry of Agriculture Development and Agrarian Services Sri Lanka
21	Mr.	Siyad	Jama	Ministery Fisheries and Marine Recourse
22	Mr.	MD AYNUL	KABIR	MONASH UNIVERSITY
23	Ms.	Claire	Kain	University of Canterbury
24		Kamran	Khajehpour	Monash University
25	Mr.	Matthew	Khoury	Corangamite Catchment Management Authority
26	Mr.	Neil	Lazarow	Australian National University & Griffith UniversitCentre for Coastal Management
27	Ms.	Helen	Martin	Gippsland Coastal Board
28	Mr.	Chris	Mason	St Quentin Consulting
29	Mr.	Doug	Miller	Department of Sustainability and Environment
30	Mr.	Hiroshi	Miyake	Kushiro Development and Construction Department
31	Ms.	Olivia	Montecillo	
32	Ms.	Louise	Munk Klint	Victoria University - Centre for Tourism and Services Research
33	Prof.	Keisuke	Nakayama	Kitami Institute of Technology
34	Ms.	Penny	Neumann	West Gippsland Catchment Management Authority
35	Mr.	YUSUFF ABIODUN	OYEDEJI	GEOTECH NIGERIA LIMITED

36	Mr	Alexis	Pang	Monash University
37	Mr.	Md. Abdul	Quadir	Dhaka City CorporationDhakaBangladesh
38	Dr.	Md.Mafizur	Rahman	Bangladesh University of Engineering and Technology (BUET)
39	Dr.	Uditha	Ratnayake	University of Peradeniya
40	Dr.	Philip	Rayment	Monash University Gippsland Campus
41	Mr.	Doug	Rolfe	Corangamite Catchment Management Authority
42	Mr.	Hironaka	Sadayuki	NEWJEC Inc.
43	Mr.	Md. Shibly	Sadik	Center of Environment and Geographic Information Services (CEGIS)
44	Mr.	Fernando	Santos	FCT/UNL
45	Mr	Momin Mozibul	Shamji	Local Government Engineering Department
46	Dr.	UTTAM CHAND	SHARMA	CENTRE FOR NATURAL RESOURCES MANAGEMENT
47	Mr.	Paul	Stampton	South Gippsland Shire Council
48	Mrs.	Jennifer	Sutton	CSIRO Marine & Atmospheric Research
49	Dr.	Geoff	Taylor	West Gippsland Catchment Management Authority
50	Dr.	Dhirendra Prasad	Thakur	Asian Institute of Technology
51	Mr	Mike	Timpano	Victorian Department of Sustainability and Environment
52	Mr.	Toshihito	Toyabe	Civil Engineering Research Institude for Cold Region
53	Mr.	Tuseef	Ullah	MEK Community Development
54	Assoc. Prof.	Ca	Vu Thanh	Research Institute for the Management of Seas and Islands
55	Mr.	Daniel	Ware	SKM
56	Assoc. Prof.	Geoff	Wescott	Deakin University
57	Dr.	Sanit	Wongsa	King Mongkut's University of Technology Thonburi KMUTT
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Proceedings of the Planning Workshop of the APN Project on

CLIMATE PERTURBATION AND COASTAL ZONE SYSTEMS IN ASIA PACIFIC REGION: HOLISTIC APPROACHES AND TOOLS FOR VULNERABILITY ASSESSMENT AND SUSTAINABLE MANAGEMENT STRATEGY

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Edited by:
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ABSTRACT

This report is the proceedings of the Planning Workshop of the APN Project ARCP2007-14NMY held in Bangkok, Thailand during 27-28 September 2007. The Project entitled "Climate Perturbation and Coastal Zone Systems in Asia pacific Region: Holistic Approaches and Tools for Vulnerability Assessment and Sustainable Management Strategy" is a project of two-year duration sponsored by the Asia Pacific Network for Global Change Research (APN) and hosted by the School of Applied Sciences of the Monash University, Australia. The project aims to develop an innovative integrated tool for accurately capturing changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing, for identifying sound metrics for assessment of impacts of these changes and for examining long-term adaptation and mitigation measures for sustainable management. The project team consists of nine collaborating researchers from six countries of the Asia Pacific region namely: Australia, Bangladesh, Japan, Sri Lanka, Thailand and Vietnam. The workshop was organized by the School of Applied Sciences and Engineering, Monash University with the local support extended by the Asian Institute of Technology, Thailand.

The main agenda of the planning workshop was to discuss the views of stakeholders' from all the participating countries and to prepare an integrated framework for development of holistic approaches and tools and their applications in the participating countries. The workshop provided a platform to all the main collaborators to present their ideas and outcomes of the Project Reference Group (PRG) meetings and detailed information on the feasible study areas identified for applications of the holistic tools. All the issues raised by the collaborators were thoroughly discussed and analysed. The planning workshop was crucial in achieving consensus and incorporating stakeholders' inputs in the project activities.

This report presents the briefing papers presented by the project members and the summaries of the discussions, which took place in the six sessions of the workshop over two days.

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APN Project ARCP2007-14NMY: Background, Objectives, Methodology, Implementation Strategy and Expected Outcomes

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1. INTRODUCTION & BACKGROUND

In recent years, there has been an increasing concern, particularly with the growing population, rapid urbanization and industrial developments in coastal areas of Asia Pacific region that the current management practices adopted in most of these countries are unsustainable (Hong *et al.*, 2002). It has been realized that the rapid developments, extraction or manipulation of resources can not exceed the sustainable limits without compromising the ecological integrity of the coastal ecosystems. This has now led to a growing concern that if the current trend of growth and exploitation continues, it would result in adverse effects on social, economic and environmental well-being in coastal zones. The extents of these consequences are further exacerbated by the adverse impacts being incurred from global climate change including extreme climatic events and sea level rises (IPCC CZMS, 1992; Titus, 1998; IPCC, 2001; Mitchell *et al.*, 2000; Dutta *et al.*, 2005).

To enable a comprehensive understanding of the changes in the physical processes due to the combined effects of climate and human-induced changes, a spatially distributed process-based integrated approach, is essential, which models the different inter-connected processes at appropriate spatio-temporal resolutions (Gordon *et al.*, 1996; Hong *et al.*, 2002; Nakayama *et al.*, 2004). A holistic approach (that combines physical modelling, vulnerability assessment with TBL and LCA principles and MCDM tools) to coastal zone management is needed to resolve the conflicting demands of society for products and services, taking into account both current and future interests (Post & Lundin, 1996; Neumann and Livesay, 2001; Walsh, 2004; APN, 2005; Dutta *et al.*, 2005). Agenda 21 (UN, 1992) and in particular its Chapter 17 'Protection of The Oceans' reaffirmed this need. Given these scenarios, the real challenge in achieving optimal sustainable management strategy in coastal zones relies on the ability to design, develop and implement an integrated management program that not only maximizes benefit to society and economy based on accurate understanding of the impacts of changes in physical processes, but that also ensures that the ecosystems are adequately protected or preserved.

In response to the need for sustainable management practices, several developed countries have developed and/or implemented sustainable coastal zone management strategies (Kay and Adler, 1999; Thom, 2002; Walsh, 2004). The developing countries in the Asia-Pacific region, still lagging behind in this front, have revealed some knowledge and approach gaps, thus presenting the opportunity to break new ground on subsequent strategies. The strategies should be the vehicle for facilitating Integrated Coastal Zone Management (ICZM) principles, but how this can be done is still unclear and yet to be demonstrated (Clark, 1992; Post and Lundin, 1996; Wlash, 2004).

2. SIGNIFICANCE AND OBJECTIVES

The project aims to develop an innovative integrated tool for accurately capturing changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing, for identifying sound metrics for assessment of impacts of these changes and for examining long-term adaptation and mitigation measures for sustainable management. Its main objective is to develop a more holistic approach and tool to apply Life Cycle Analysis (LCA) principles to the coastal zone systems in cross-cutting issues in the Asia Pacific region. In doing so, this project intends to overcome the limitations of the existing fragmental approaches for evaluating more complex and interrelated biogeochemical and physical processes in coastal zones that include nutrient flux, salinity, floods, erosion and sedimentation and their impacts on society, economy and environment. To achieve these goals, the project will focus on selected coastal zones which will have all of these attributes in six countries within the Asia Pacific region. A major expected outcome of the project is to develop multi-criteria decision-making and fuzzy preference models that will support broad stakeholders' engagement in regional coastal zone sustainable management strategy.

3. METHODOLOGY & IMPLEMENTATION PLAN

The project takes a systematic approach for developing a holistic assessment methodology and prototype and its implementation (Fig. 1). The proposed holistic assessment tool comprises three major components as described below (Fig. 2):

1) Process model (PM):

An integrated process model will be built on existing and new scientific knowledge of different physical processes in coastal zone systems including hydrological and biogeochemical processes and their exchange through water and soil and pathways in the river catchment and coastal sea interactions for scientific understanding of changes in these processes due to combined effects of global climate change and anthropogenic developments (Gordon *et al.*, 1996, Hong *et al.*, 2002; Nakayama *et al.*, 2004; Garnier *et al.*, 2005; Bhattarai and Dutta, 2005; Nakayama, K., 2005; Dutta *et al.*, 2006).

2) Impact Assessment Tool (IAT):

All the social, economic and environmental factors affected by changes in the physical processes will be identified and a set of criteria, indicators and appropriate response functions relating to the changes will be established. Using these functions and predictive outcomes of modelling of physical processes, detailed quantitative assessment of social, economic and environmental impacts in coastal zones under climate changes and anthropogenic developments will be carried out.

3) Multi-Criteria Decision Making and Support System (MCDMSS):

A set of criteria and indicators will be developed representing social, economic and environmental sustainability of coastal zone systems. Fuzzy Preference modelling with multi-objective optimisation approach will be used to model the stakeholders' preferences and expectations in the decision appraisal process (Doloi and Jaafari, 2002; Manivong *et al.*, 2004). Using these criteria and indicators, a multi-criteria decision making system will be established for strategic planning, policy development and enhancement and pathways for sustainable management of coastal zones.

The project will be carried out in five distinct phases as follows:

Phase 1: Planning

Establishment of a Project Reference Group (PRG) in each member country involving APN national focal points, stakeholders from government, non-governmental and industry sectors at local and national levels to identify the current practices, needs, expectations, preferences and gaps for setting up benchmark for integrated project framework development and for selecting most feasible study areas.

Phase 2: Data and Information Collation

Collection and collation of key data and relevant information via reputable sources will be required:

i) to develop a systems perspective that identifies the baseline situation with regard to nutrient flux, salinity, floods, erosion and sedimentation,
ii) to conduct prognostic analysis of physical processes due to long-term climatic perturbation and anthropogenic developments,
iii) to develop relationships between changes in physical processes and their impacts to society, economy, ecosystems and biodiversity,
iv) to develop social, economical and environmental sustainable criteria and indicators for MCDM analysis.

Phase 3: Development of Integrated Assessment Tool

Use collated data and information to develop a process-based distributed hydro-biogeochemical model, impact assessment tool for socio-economic and environmental impact assessment and decision support system for analysing options identified by stakeholders in relation to one another based on Triple Bottom Line (TBL) and LCA principles.

Phase 4: Scenario analysis

Application of the integrated tool for scenario analyses in the selected case study areas;

i) for prognosis of changes in physical processes in coastal system under climate change and anthropogenic developments in 2025, 2050, 2075 and 2100,
ii) assessment of socio-economic and environmental impacts under prognostic changes,
iii) for analysing social, economic and environmental sustainability for different management strategies identified by the key stakeholders.

Develop and model 'what if' scenarios to test sensitivity of a range of whole system impacts. These scenarios would provide key data to support community consultation programs ahead of implementing change.

Phase 5: Recommendations report, awareness campaign and capacity building

a. Develop a set of recommendation in collaboration with the stakeholders that:
    a. details key issues
    b. prioritises areas of actions on the basis of whole system assessment using long term sustainability principles that consider quantitative and qualitative aspects
    c. Recommends preferred implementation approaches for priority options
    d. Specific actions required by government and non-governmental agencies, industry sectors to ensure sustainable management of coastal zone system
b. Conduct awareness campaign through public for a and distribution of project outcomes
c. Organize training sessions for application of the assessment system by stakeholders for independent applications in different countries in Asia-Pacific region

4. POTENTIAL OUTCOMES

The major expected outcomes are: 1) a holistic tool with LCA and TBL principles to the coastal zone systems in cross-cutting issues for sustainable management; 2) a policy report that details key issues, prioritizes areas of actions, recommends preferred implementation approaches, and specifics actions to ensure sustainable management of coastal zone system, 3) enhancement of public awareness and institutional capacity to support broad stakeholders' engagement in sustainable strategy. The host country will maintain and upgrade project products, database and web-based communication system for future research and development. The collaborators will continue to apply the tools in coastal areas in their countries and assist in decision-making process. These activities will significantly contribute to the self-sustainability of the project.

REFERENCE

APN (2005). APN Strategic Plan (2005-2010), Asia-Pacific Network for Global Change Research, Kobe, Japan, 20pages.

Belfiore, S. (2003). The growth of integrated coastal management and the role of indicators in indicators in integrated coastal management: introduction to the special issue. Ocean and Coastal Management 46, 225-234.

Doloi, H. and Jaafari, A. (2002) "Towards a Dynamic Simulation Model for Strategic Decision Making in Life Cycle Project Management" Project Management Journal, Vol. 33 (4), December 2002, 23-38.

Dutta, D., M.S. Babel and A. Das Gupta (2005). An Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas, Final Report for APN CAPaBLE Project: 2004-CB01NSY-Dutta, Asian Institute of Technology, ISBN 974-93908-0-6, 205 pages.

Gordon, D.C. Jr., P.R. Boudreau , K.H. Mann, J.-E. Ong, W.L. Silvert, S.V. Smith, G. Wattayakorn, F. Wulff, and T. Yanagi. (1996). LOICZ Biogeochemical Modelling Guidelines, LOICZ Reports & Studies No. 5. Second Edition, vi +96 pp. LOICZ, Texel, The Netherlands.

Hong, G.H., H.H. Kremer, J. Pacyna, Chen-Tung Arthur Chen, H. Behrendt, W. Salomons and J.I. Marshall Crossland (2002). LOICZ Global Assessment and Synthesis of River Catchment-Coastal Sea Interaction and Human Dimensions. East Asia Basins, LOICZ Reports & Studies No. 26, ii + 262 pages, LOICZ IPO, Texel, The Netherlands

IPCC (2001). Climate Change 2001: The Scientific Basis. Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Van der Linden, P.J., and Xioasu, D. (eds.), Cambridge and New York: Cambridge University Press, 881 pages.

Kay, R., and J. Adler (1999). Coastal Planning and Management. Routledge, 375 pages.

Nakayama, K., D. Dutta, G. Tanaka and T. Okada (2004). Integration of Hydrological Model and Estuary Model, Journal of Japan Society of Hydrology and Water Resources, 18(4), 390-400.

Neumann, J.E. and N.D. Livesay (2001). Coastal structures, dynamic economic modeling. In: Mendelsohn, R. (ed.), Global warming and the American economy , a regional assessment of climate change impacts. Cheltenham, U.K.: Edward Elgar, 132-148.

Post, J. C and C. G Lundin (1996), Guidelines to Integrated Coastal Zone Management, World Bank, Washington DC.

Thom, B.G. (2002) CZM in NSW: The Good, the Bad and the Ugly. In: Coast to Coast 2002, proceedings, 468-470.

UN (1992). Agenda 21: Earth Summit - The United Nations Programme of Action from Rio, UNCED Earth Summit of 1992, 294 page

Walsh, K. (2004). Climate Change and Coastal Response, A theme report from the Coast to Coast 2002 National Conference, Gold Coast, November 2002, Melbourne University, Australia, 34p.

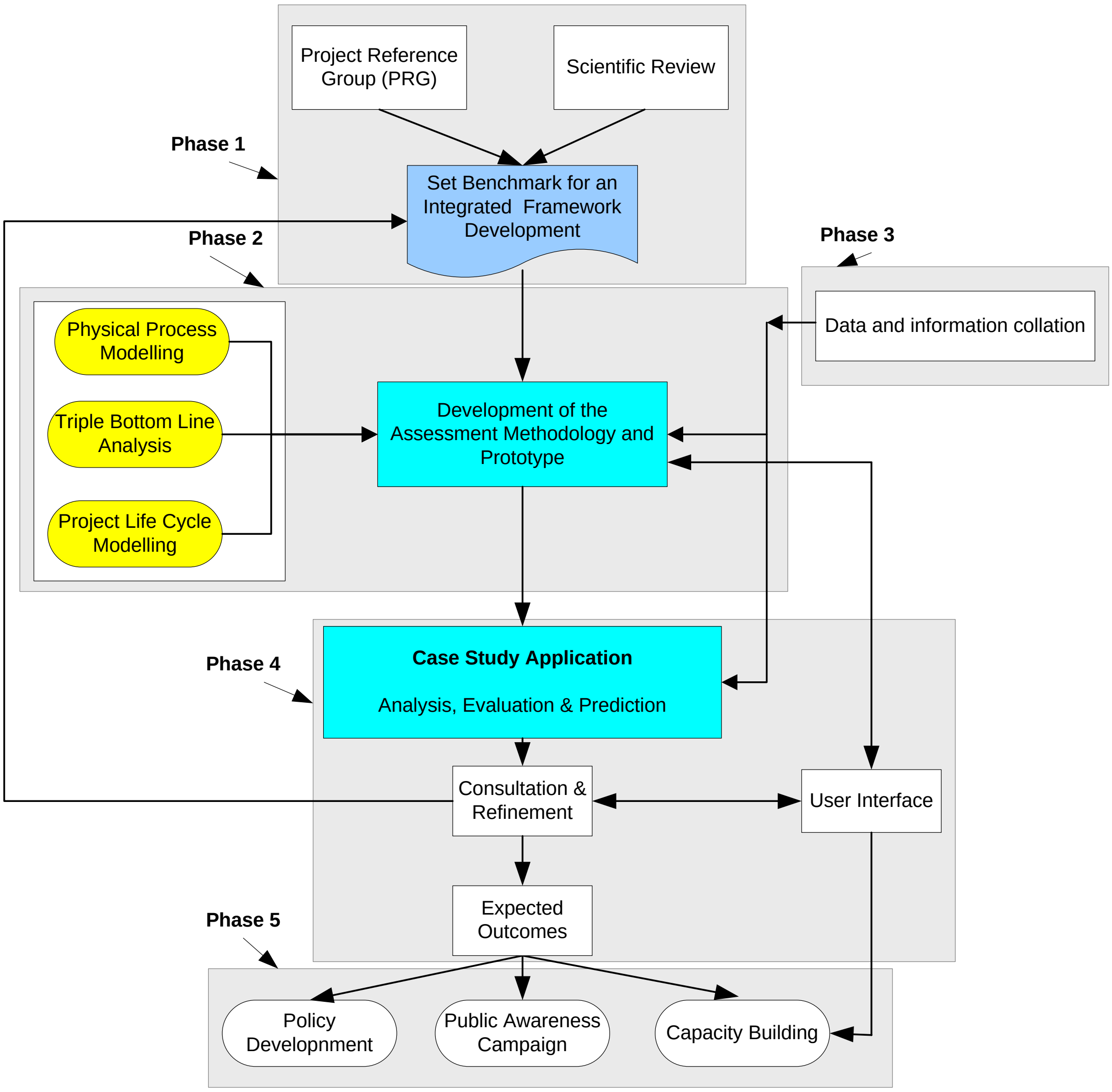

Fig. 1: Project Framework

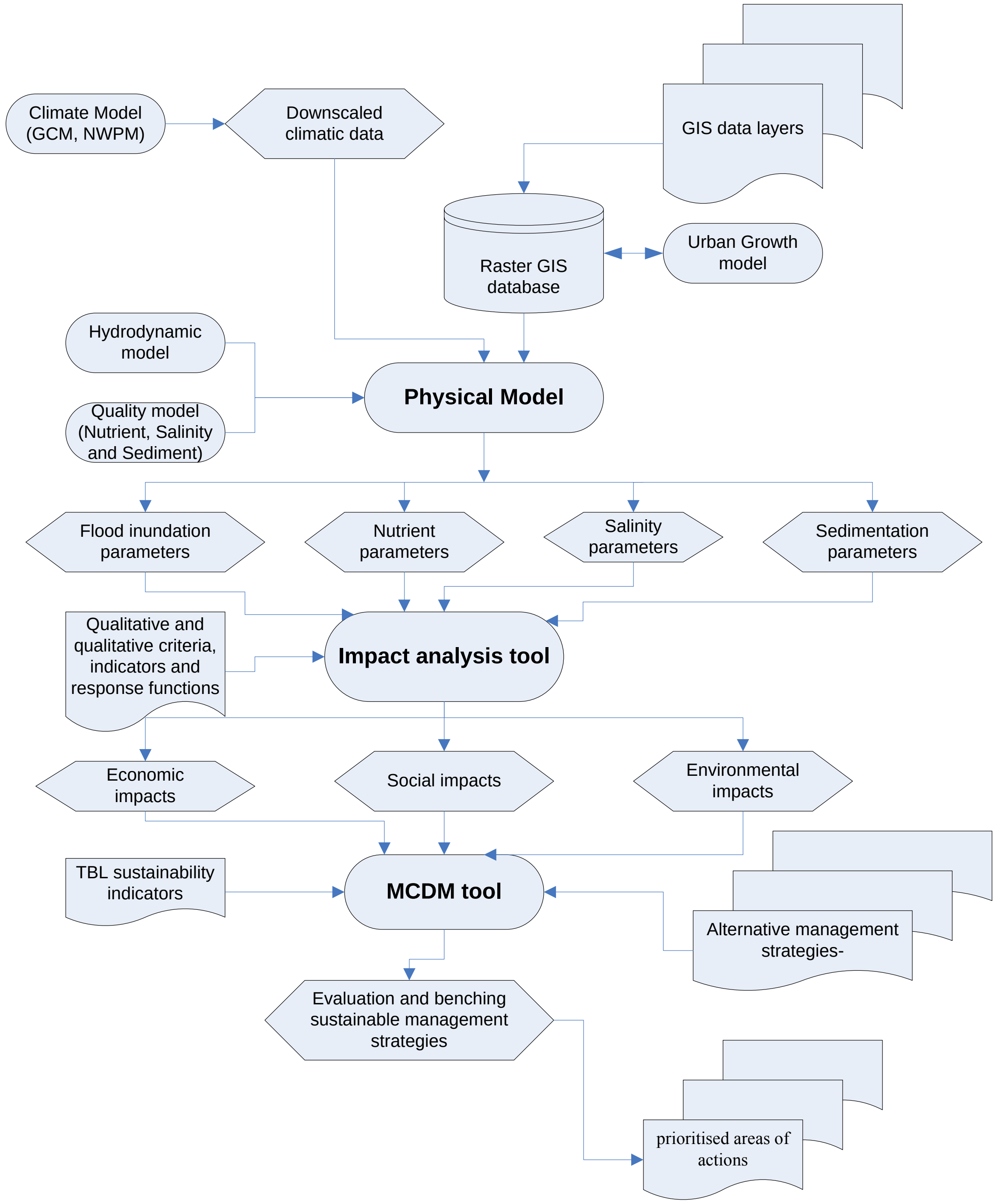

Fig. 2: Project Methodology

Potential Impacts of Climate Variability and Anthropogenic Forcing on Water Quality in Gippsland Lakes

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1. INTRODUCTION & BACKGROUND

The Gippsland Lakes comprise of three distinct lakes, namely lakes Wellington, Victoria and King, linked by the McLennan Strait. These lakes are now well recognized as a major natural resource with economic, environmental and cultural significance. However, the benefits and attractions offered by the lakes have been compromised over the years by many undesirable changes in water quality caused by various stressors, such land use (mainly agriculture), land use change, pollution and eutrophication (Green, 1978; Pitt and Synan, 1987; Harris et al., 1998; Webster and Wallace, 2000; Longmore, 2000; Grayson et al., 2001; Webster et al., 2001). An environmental audit of available data on the lakes catchment revealed, as evident in Table 1, that the largest load contributed to the Gippsland Lakes was from suspended solids with an average of 636,600 tonnes per annum (Harris et al., 1998). Majority of this load was contributed by Thomson, Tambo, Latrobe and Macalister rivers. The Latrobe river was also identified as the largest source of total phosphate, orthophosphate and nitrate/nitrite. Figure 1 shows how these and other rivers feed directly into the lakes. The study also revealed that the periodic concentration of total phosphorus in the lakes can be as high as 110 µg/L or more, while the concentration of total nitrogen can be as high as 1500 µg/L or more (Harris et al., 1998). A more recent study (Webster et al., 2001) has revealed that the Gippsland Lakes faced two major water quality concerns: (a) recurring blooms of the blue-green, cyanobacterium *Nodularia* algae; and (b) extended periods of bottom water hypoxia, which results in the reduction of oxygen concentration due to bacterial consumption of algal detritus. This has led to increased efforts to reduce nutrient loads within the lakes. Some of the specific considerations in the on-going study include identification of factors influencing water quality and algal blooms. This study will therefore be useful in predicting the impact of climate variability on water quality and the likely frequency of algal blooms.

2. SIGNIFICANCE

The impact of climate variability on water quality within the Gippsland Lakes is of considerable significance, particularly with regards to nutrient concentrations, salinity and the occurrence of blue-green, cyanobacterium *Nodularia* algae. Mobilization of contaminants that have accumulated in sediments within the lakes and sources external to the lakes due to extreme weather events can severely alter nutrient concentrations and salinity, and thus influence the frequency of blue green algae. It is expected that the predictive models developed in this study will enable varied and robust identification of the impacts of different climate change scenarios on water quality in the lakes. Of particular interest is the impact of an inadequate storm water infrastructure and poor management of urban runoff could have on the water quality in the lakes if total annual rainfall and the intensity of specific storm events increase or decrease.

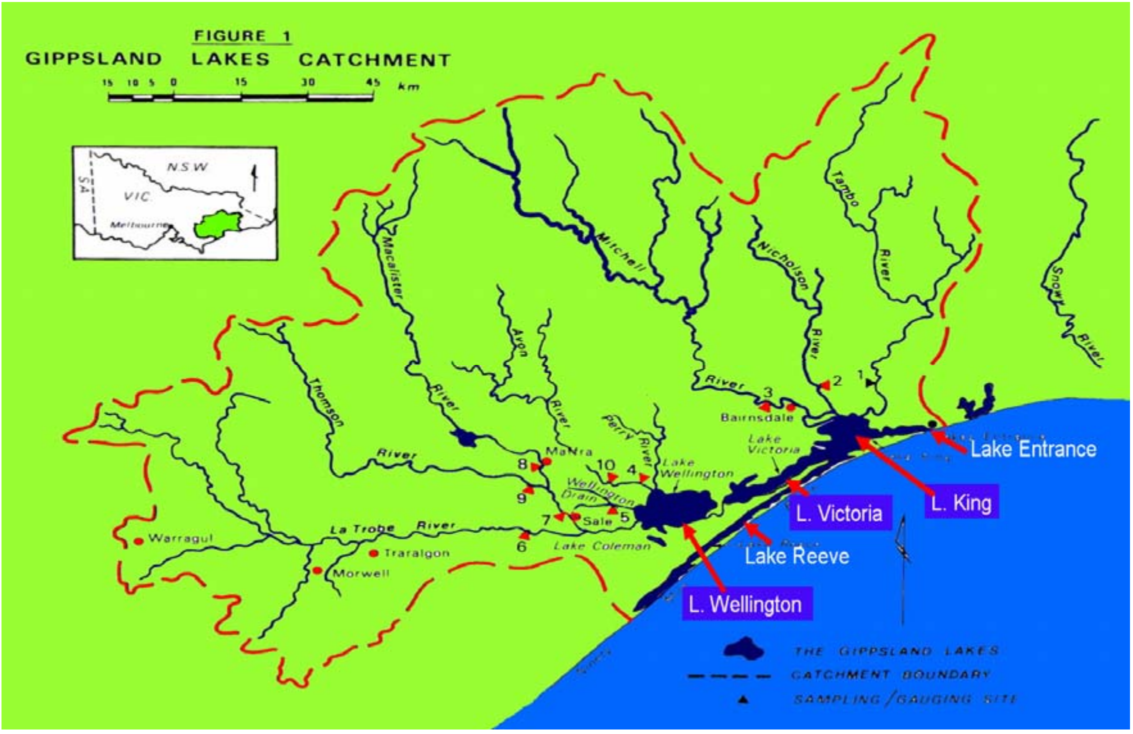

Fig. 1: Map of the Gippsland Lakes Catchment

Table 1: Calculated average annual loads (tonnes) from rivers to the Gippsland Lakes

	Tambo River	Nicholson River	Mitchell River	Avon River	Latrobe River	Thomson River less Macalister	Macalister River	Gippsland Lakes Total load
Total Phosphate	29	14	77	16	122	81	65	400
Ortho Phosphate	12	3	13	3	27	22	13	94
Nitrate/Nitrite	103	46	145	25	447	52	70	889
Total Kjeldahl	770	150	770	150	870	200	380	3,290
Ammonia	13	3	6	4	34	-6	36	96
Silica	2,480	2,600	9,020	1,490	7,530	4,090	3,160	30,370
Suspended solids	112,200	18,800	92,900	26,800	111,800	164,500	109,600	636,600
TDS (EC at 25 °C x 0.6)	29,600	14,800	93,200	16,500	139,600	23,900	24,500	342,100
Daily Avg Flow (ML/day)	1,133	251	3,132	513	2,504	1,470	1,363	10,476
Catchment area (km^2)	2,876	530	4,778	1,650	4,785	1,648	2,012	20,999

Reproduced from Harris et al., 1998.

3. CONCEPT DETAILS

Human activities and ecosystem functioning within the Gippsland Lakes and its surroundings is very much dependent on climate. Changes or variation in climate could alter various effects or factors, such as air, soil, and water quality; water supply; sea level rise; the frequency and severity of droughts and floods; ecosystem health; human health; and resource use and the economy. Within this context, the interactions in and impacts on the Gippsland Lakes ecosystem can be dynamic and non-linear due to and dependent on the extent of climate variability. Hence, climate variability could thus be considered as another factors acting together with other ecosystem stressors. The ability to identify potential impacts and possible adaptation strategy is therefore critical for responding to and managing the implications of a changing climate on the Gippsland Lakes watershed (Figure 1). Thus, the ability of the predictive models to be employed in this study to provide a good understanding or appreciation of the magnitude and consequences of climate variability on water quality (particularly in relation to nutrients, salinity and turbidity) in the Gippsland Lakes (and other case studies) will be useful for identifying and implementing appropriate management practices to curtail its impact.

4. POTENTIAL OUTCOMES

In broad terms the proposed integrated tool, which comprise of a process model, impact assessment tool, and multi-criteria decision making and support system, will enable:

a. Accurate capture of the impact of climate change and anthropogenic forcing on hydro-biogeochemical processes in coastal zone systems;
b. Identification of sound metrics for assessment of the impacts of resulting changes based on triple bottom line concepts; and
c. Examination of long-term adaptation and mitigation measures for sustainable management.

More specifically, a significant benefit of the integrated tool is that it can explore vulnerability or sensitivity of the water quality in Gippsland lakes (and in case studies from other countries) to current climate extremes and thresholds of changes. In a broader sense, it is expected that the research undertaken will reflect both the stakeholder and researcher views of what is needed to understand the extent of climate variability, the impacts, and adaptive responses in the six participating countries. The PRG and this workshop have provided the ideal opportunities for identifying and compiling the necessary research needs, as well as to reflect on and identify similarities and differences. Further refinement of the ideas through dialogue within the various communities in the participating countries on what needs to be done to address impact of climate change will also be beneficial in ensuring that concern of stakeholders have been duly considered.

REFERENCE

Grayson, R., Tan, K.S. and Wealands, S. (2001) *Pre-European load estimates into the Gippsland Lakes*, Centre for Environmental Applied Hydrology, University of Melbourne, Australia.

Green, O.S. (1978) *The Gippsland Lakes*, Rigby Limited, Australia.

Harris, G., Batley, G., Webster, I., Molloy, R. and Fox, D. (1998) *Review of Water Quality and Status of the Aquatic Ecosystem of the Gippsland Lakes*, CSIRO Environmental Projects Office, Australia.

Longmore, A.R. (2000) *Gippsland Lakes sediment nutrient inventory*, Marine & Freshwater Resources Institute, Department of Natural Resources and Environment, Australia.

Pitt, M.W. and Synan, T.P. (1987) *The Past, Present And Future of The Gippsland Lakes*, The Save The Gippsland Lakes Committee, Australia.

Webster, I.T. and Wallace, B. (2000) *Further Analysis of Sediment Core Samples Collected in the Gippsland Lakes*, CSIRO Land & Water, Australia.

Webster, I.T., Parslow, J.S., Grayson, R.B., Molloy, R.P., Andrewartha, J., Sakov, P., Ian, K.S., Walker, S.J. and Wallace, B.B. (2001) *Gippsland Lakes Environmental Study – Assessing Options for Improving Water Quality and Ecological Function*, CSIRO, Australia.

Impacts of Climate Perturbations on Ecosystems & Ecosystem Processes

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1. INTRODUCTION & BACKGROUND

This project, funded by the Asia Pacific Network for Global Change Research, aims to design a model which will help us understand the causes and consequences of climate perturbations in coastal zone systems in the Asia Pacific Region. The focus is on flooding, nutrients, salinity and sedimentation in coastal locations in six countries.

In Australia, we have chosen the Gippsland Lakes as the case study location. The Gippsland Lakes are a series of coastal lagoons – large, areas of shallow water that have been almost wholly sealed off from the sea by a coastal dune system. "The Lakes" are Australia's largest navigable inland waterway and include three main water bodies: Lake Wellington (138km^2) in the west, fed by the La Trobe, Thompson, Macalister and Avon Rivers, and linked by the McLennan Strait to Lake Victoria (110km^2) and Lake King (92km^2) (Boon *et al.,* 2007a). An artificial entrance was cut to the ocean in 1889 at Lakes Entrance, about 5km from the natural shifting and intermittent outlet which opened during large flood events (Boon *et al*., 2007aa).

The area is not highly populated, but there are significant infrastructure investments and it is an important area for tourism and recreational fishing. The area also has significant ecological importance and includes Ramsar listed wetlands.

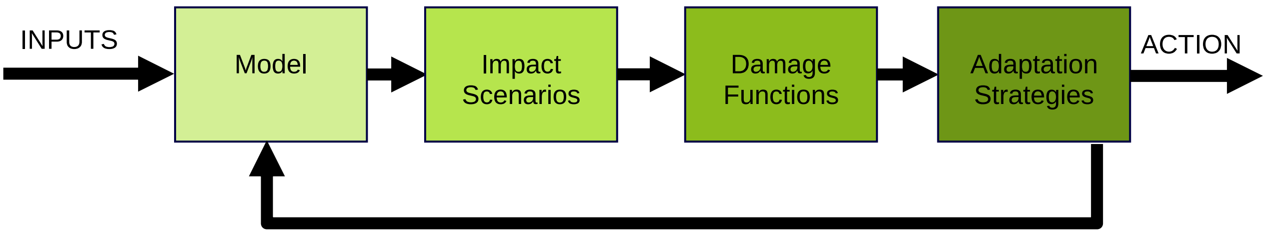

Figure 1: Conceptual steps in modelling Climate Change Impacts on Flooding, Nutrients, Salinity and Sedimentation in the Gippsland Lakes

As a biologist, my contribution to the project is to identify inputs which are likely to affect ecosystem processes; and to assist in estimating appropriate damage functions for ecosystems and ecosystem processes.

2. SIGNIFICANCE

Ecosystems and ecosystem processes are poorly understood, even where they exist in stable climatic conditions. We do not understand the likely outcomes of changes in flooding, nutrient, salinity and sedimentation regimes on ecosystems and ecosystem processes; or how such changes will affect the ability of the ecosystem to support physicochemical, geomorphological and economic characteristics of any particular location.

This project will allow us to develop impact scenarios ("what if" scenarios) for different flooding, nutrient, salinity and sedimentation regimes at the Gippsland Lakes. Identification of tipping points and damage functions will allow us to move proactively towards adaptation to climate perturbation.

3. CONCEPT DETAILS

Stakeholders at the Australian Project Reference Group meeting identified several areas of concern regarding impacts on biodiversity and ecosystem processes due to changes in flooding, nutrient, salinity and sedimentation regimens at the Gippsland Lakes. In many cases, perturbations in the physical environment can alter ecosystem processes, which further perturb the physical environment. Compounding of impacts can therefore occur.

For example:

- We can model impacts of increasing salinity on Common Reed (*Phragmites australis* – a fringing reed). Increased salinity due to salt water incursion since the establishment of a permanent opening has lead to death of reed beds, exposing the shoreline to erosion. What will happen if increased storm surges create additional breaches in the dunes, further increasing salinity by salt water incursions *and* increasing wave action at vulnerable places on the lake shore? (Gippsland Coastal Board, 2003)

- There are eight species of flathead in Victoria – these are important fish species for recreational fishers. The most common is the Dusky Flathead - *Platycephalus fuscus.* Distributions of these fish alter with patterns of saline and fresh water profiles in the lakes, but we do not know the effect of such changes in distribution.

Damage functions for ecosystem processes may also be more complex than for infrastructure or crops (this is due to the difference in complexity between a whole ecosystem and a monoculture).

For example:

- Wetland ecosystems are threatened by rising saline groundwater as a result of clearing of native vegetation and require intermittent flooding to leach salts into the groundwater table. Saltwater incursions may exacerbate this problem. Essentially, inputs regarding salinity levels should be accompanied by data describing spatial and temporal characteristics of the wetland's wetting and drying cycle (the timing, duration and *frequency* of flooding; the rate of water rise and fall, the maximum water depth etc) as well as information regarding the source of the water (specifically the relative input of water from rainfall, surface water runoff, sea water intrusions and upwelling of groundwater) (Boon *et al*. 2007b). Such a comprehensive approach is important in creating appropriate damage functions.

4. POTENTIAL OUTCOMES

Outcomes of this project will include:

- Identification of commonalities and differences between stakeholder concerns for the case study areas in the six participating countries
- Better understanding of the relationships between climate-driven perturbations (in flooding, nutrients, salinity and sedimentation) and ecosystem function
- Better understanding of the damage functions relating to ecosystem processes
- Identification of tipping points for large scale changes in ecosystems and ecosystem processes at the Gippsland Lakes

- A better understanding of the potential for changes in physicochemical and geomorphological characteristics of the case study site to impact on ecosystems and ecosystem processes and the extent to which these may compound to produce drivers for further change
- An assessment of the likelihood that the whole system will change (if the barrier dunes are permanently breached)

REFERENCES

Boon, P., Raulings, E., Morris, K., Roache, M., Robinson, R., Hatton, M. and Salter J. (2007a) “Ecology and Management of the Lake Wellington Wetlands, Gippsland Lakes. A report on the R&D Project, 2003-2006. Monash University & Victoria University.

Boon, P., Raulings, E., Morris, K., Roache, M. and Bailey, P. (2007b) “Managing Water Regimes in High-Value Wetlands: General approaches, emerging technologies and specific applications”. Monash University & Victoria University.

Gippsland Coastal Board (2003) “Shore Erosion Around the Gippsland Lakes” Learn About the Lakes Information Sheet #L7

Selection of Optimal Strategies for Sustainable Management using Multi-Criteria Decision Making (MCDM) approach

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1. INTRODUCTION & BACKGROUND

Environmental related problems often characterised by complexity, irreversibility and uncertainty. Addressing of such problems in an holistic approach and developing an appropriate sustainable management strategy is a challenging task. Under such circumstances, evaluation methods like simple cost-benefit analysis or financial impact analysis are ill-suited because improvements in one problem dimension cannot compensate for deterioration in another dimension (Munda 1995). Rather, the goal of evaluation should be to determine a ranking of alternatives according to the pre-set criteria. Multicriteria decision analysis (MCDA) is usually found useful as it can help decision makers to evaluate problems involving conflicting objectives, since they can take simultaneously into account several sources of judgement even if measured in different units. Under such difficult conditions MCDA methods foster rationality in decision-making and can support decision making as a process. In this sense evaluation constitutes an instrument which is able to enhance political, socio-cultural as well as technical debate, helping to build consensus and the control the quality on alternative feasible proposals.

2. SIGNIFICANCE

Environmental decision making usually involves competing interest groups, conflicting objectives and diverse information types. Frequently these dimensions are reduced using single objective framework with narrow focus. In contrast, multicriteria decision analysis (MCDA) obeys incommensurability of parametric values without a common unit of measurement across plural values. Comparison of criteria in different units of measurement (imcomparability) is allowed in the MCDA.

In this research, all the social, economic and environmental factors affected by changes in the physical processes need to be identified and a set of criteria, indicators and appropriate response functions relating to the changes require to be established. Fuzzy Preference modelling with multi-objective optimisation approach will be used to model the stakeholders' preferences and expectations in the decision appraisal process (Doloi 2007; Manivong et al., 2004).

Using these functions and predictive outcomes of modelling of physical processes, detailed quantitative assessment of social, economic and environmental impacts in coastal zones under climate changes and anthropogenic developments will be carried out in MCDA framework. The outcome will assist in strategic planning, policy development and enhancement and pathways for sustainable management of coastal zones.

3. METHODOLOGY & IMPLEMENTATION PLAN

The multicriteria evaluation process includes four major steps: i) selecting the evaluation criteria and sub-criteria; ii) criteria scores; iii) determine criterion's priority; and iv) multi-criteria evaluation and ranking the different alternatives. A brief description of the application of these steps is presented below.

Evaluation Criteria and sub-criteria

A criterion is defined as "a measurable aspect of judgement by which a dimension of the various choice possibilities under consideration can be characterised" (Voogd, 1983). In this research, the inductive approach is used to select the criteria. An inventory of all the choice of possibilities is done, then grouped and aggregated them in such a way that a set of evaluation criteria arises.

Criteria Score

The characteristics of the choice possibilities under consideration are represented by means of criteria's scores. These scores reflect to a certain degree an alternative meets a certain criterion. Criteria's scores can be derived in many different ways. They may be the result of a thorough investigation or the outcome of an intuitive estimation by experts. The scores may end up with quantitative or qualitative scores.

Criteria Priority

The relative importance of criteria and criterion scores to one another is reflected by priorities or weights. From an application point of view it appears that such priorities can affect the final evaluation results. There are many ways to assign weight for the different criterion such as paired comparison, complete ranking, seven point scales and rating. In this study, the fuzzy ranking is used to apply preference for the criterion. Fuzzy ranking is very attractive because its accuracy does not decrease with the increase of criteria numbers. Consequently, the weights are calculated by standardising the fuzzy rank orders.

Multicriteria Evaluation

The basic mathematical approach for the multicriteria evaluation depends on a filling an evaluation matrix for all the possible alternatives and evaluation criteria as presented in Figure 2 and Table 1. Next to this matrix there are the different proposed preferences or weights for each criterion as presented in Table 1. Through the different methods of solving such matrix, results are appeared in what defined as the appraisal scores. The conclusion may therefore be the selection of alternate with the best score.

4. POTENTIAL OUTCOMES

The following outcomes are expected from the application of the MCDM analysis:

a. A methodology for evaluating sustainable management scenarios has been formulated.
b. Evaluation of different scenarios is based on multicriteria rather than the common evaluation that is based on single criteria).
c. The methodology allowed the social, economic, environmental issues to be considered in sustainable policy formulation.
d. Criterion's selection and assigned weights influence the results significantly.
e. Transparency of the techniques gives the opportunity to resolve the conflicts among different stockholders.

REFERENCE

Doloi, H. (2007), "Developing an Integrated Management System for Optimising Project Options", Journal of Enterprise Information Management, Vol.20, No.4, pp.465-486.

Doloi, H. (2006), "A framework for managing front-ends of complex projects incorporating simulation based approach", Journal of Chinese Institute of Industrial Engineers, JCIIE, 23 (6), 458-467.

Dyer, R.F. and Foreman, E.H. (1992), "Group decision support with Analytical Hierarchy Process", *Decision Support Systems,* Vol.12(1), pp.23-33.

Hyde, K., Maier, H. and C. Colby (2003). “Incorporating uncertainty in the PROMETHEE MCDA Method”, *Journal of Multi-Criteria Decision Analysis,* Vol 12, pp245-259, 2003.
Munda, G. (1995), Multicriteria Evaluation in a Fuzzy Environment, Heidelberg: Physica-Verlag.
Manivong, K. Jaafari, A., Gunaratnam, D., and Doloi, H. (2004) “Architecture of an Intelligent Project Management Information System for Optimistic Capital Projects” Proceedings of the World IT Conference for Design and Construction, INCITE 2004, 515-522.
Voogd, H. (1983), Multicriteria Evaluation for Urban and Regional Planning, London: Pion.
Saaty, T.L (1980). “The Analytical Hierarchy Process”, McGraw-Hill, New York.

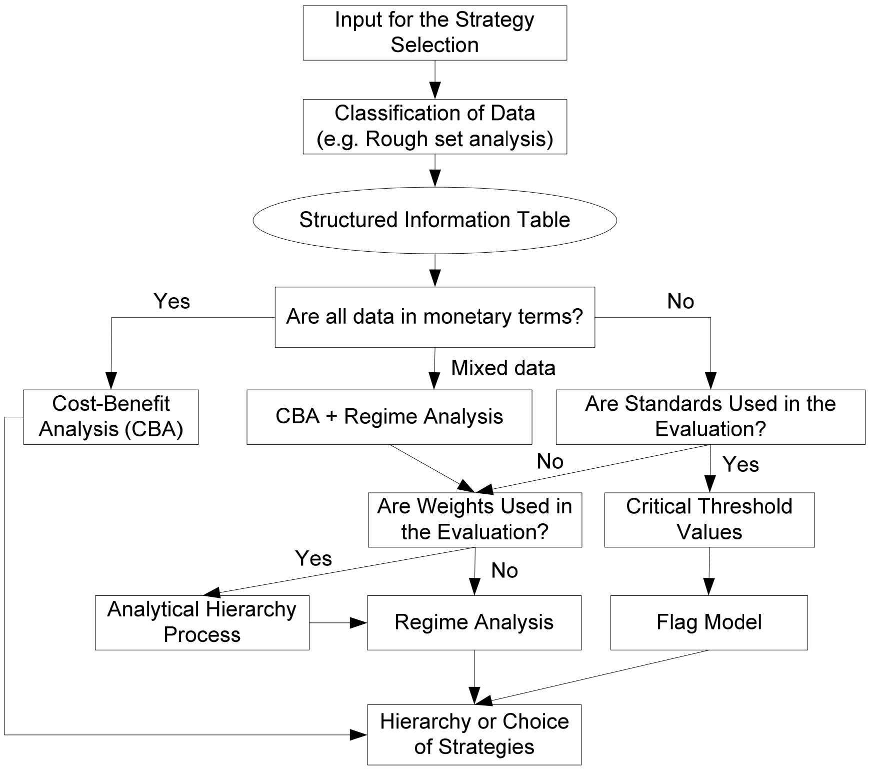

Figure 1: Steps in evaluation methodology

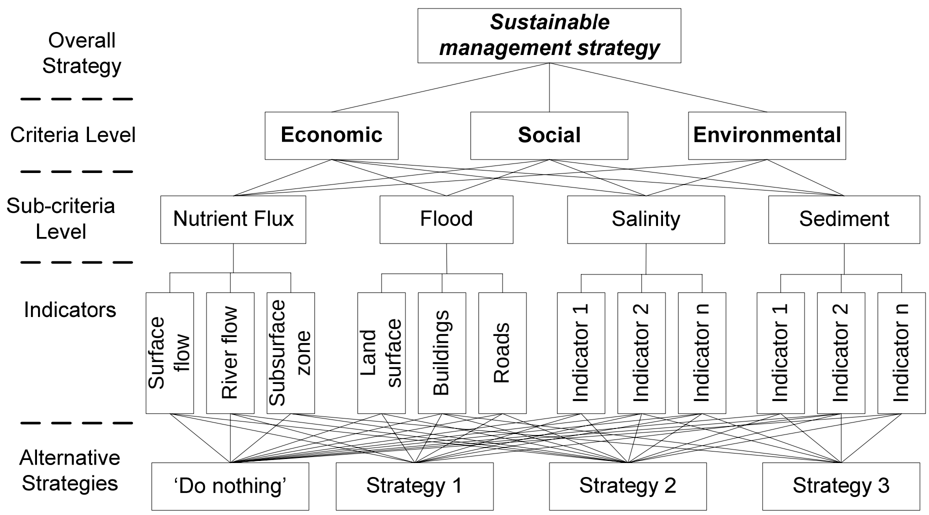

Figure 2: Illustration showing hierarchy structure for collecting relevant data

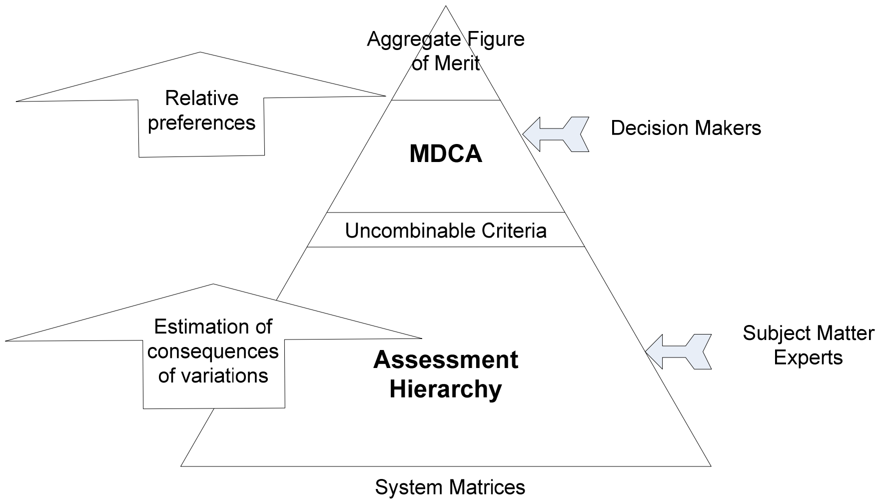

Figure 3: Illustration showing distinction between assessment hierarchy and MCDA

Table 1: Collection of Raw Data to use in Evaluation Process

Main Criteria	Sub-criteria	Indicators	Type	Scale	Relative ranking (1-9)		
					Min. limit	Likely limit	Max. limit
Economic	Nutrient Flux		Benefit	Quantitative	3	5	7
			Benefit				
	Salinity		Disbenefit	Qualitative			
			Benefit				
	Flood		Disbenefit	Quantitative			
			Benefit				
	Sediment		Disbenefit				
Social	Nutrient Flux			Quantitative			
	Salinity						
	Flood			Quantitative			
	Sediment						
Environmental	Nutrient Flux						
	Salinity						
	Flood						
	Sediment						

Integrated Approaches and Tools for Vulnerability Assessment and Sustainable Management Strategy for Coastal Zone of Bangladesh

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1. INTRODUCTION & BACKGROUND

Coastal zone of Bangladesh has been delineated considering the influence of tidal actions, saline water intrusion and storm/surges. 147 Upazillas of 19 Districts of the southern part of the country and Exclusive Economic Zone (EEZ) in the Bay of Bengal constituted the coastal zone of Bangladesh. This area of the country, like other areas of the world are resourceful but it also paces vulnerabilities like cyclone, storm surge etc.

Recently, Bangladesh has completed the Integrated Coastal Zone Management Plan Project (ICZMPP). This project has evolved the concept of reducing the vulnerabilities of the coastal lives (of all living organisms), for improving the living standard of costal people by enhancing their livelihood capacities (poverty reduction) and to coordinate and harmonize the development activities of all implementing agencies working in coastal area for maintaining a healthy eco-system.

The project activities were structured through six outputs: (i) Coastal Development Strategy (CDS), (ii) coastal zone policy (CZPo), (iii) priority investment program (PIP), (iv) models of good practice to enhance the capacity of communities to improve their livelihoods, (v) enabling institutional environment and (vi) integrated coastal resources knowledgebase.

The major issues of coastal zone of Bangladesh are cyclonic storm, tidal surges, impact of climate change, erosion, water logging, salinity intrusion, potential threat of tsunami, reduction of natural resources, scarcity of potable water, arsenic pollution in water, lack of contemporary sanitary latrine and lack of facilities (electricity, health and others). Lack of water purification facilities and contemporary sanitary system are also hampering the coastal lives.

However, the coastal zone is resourceful and very potential for its unlimited marine resources, possibilities of land reclamation, environmental friendly shrimp culture, fish farming, dry fish industry, coastal farming, forestation, salt farming, port & harbor industry, oil & gas, wind & solar energy, different mineral resources and opportunities for tourism.

2. SIGNIFICANCE

As the coastal zone of Bangladesh is full of different natural resource, it is necessary to develop integrated approach for improvement of coastal resource management. To identify and understand the different hydro-biogeochemical processes in coastal zone systems and impact of climate change and anthropogenic forces on the processes are essential in integrated manner. An innovative and interactive tool will be developed through this project for accurately capturing changes in hydro-biogeochemical processes in coastal zone for identifying sound metrics for assessment of impacts of these changes and for examining long-term adaptation and mitigation measures for sustainable management.

3. CONCEPT DETAILS

A framework will be developed prior to the implementation stage of the project. The hydro-biogeochemical processes of coastal zone systems in the context of climate change and anthropogenic forcing will be identified. After identifying all components of anthropogenic development and climate change, they will be detailed out and segregated. The impacted processes of climate change and anthropogenic forcing will be recognized. Then different framework will be developed for hydro-biogeochemical processes of coastal zone system in the context of climate change and anthropogenic forces and they will be interlinked.

Based on scientific knowledge and recent development in the coastal zone of Bangladesh, an integrated process model will be developed as per physical processes including hydrological and biogeochemical processes. An indicator based tool will be developed considering the social, economic and environmental factors with set of criteria and appropriate response functions. Ultimately a multi objective optimizing techniques will be used to incorporate the stakeholders' preferences, which will lead to decision making process. This multi criteria decision making system will help for strategic planning, policy development for sustainable management of coastal zone of Bangladesh.

4. POTENTIAL OUTCOMES

The major potential outcomes of the study projects are:

a. Framework for understanding of different hydro-biogeochemical processes in the coastal zone of Bangladesh;
b. Coastal Zone Information System (CZIS)
c. Tool for vulnerability assessment

Impact of Sea Level Rise on Flood Events and Ecosystem in Coastal Areas

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1. INTRODUCTION & BACKGROUND

Climate change and sea level rise or sea level change have been found to occur over the world. Climate change has induced higher category typhoons and sea level rise would increase disaster due to storm surges or flood events. In Japan, although coastal areas occupy 32% of the land, 46% of the population is in the coastal areas. Therefore, disaster due to flood or storm surge would cause much more serious damages in the areas.

In Hokkaido area, there are the regions which have been registered by Ramsar treaty, like Kushiro wetland, Lake Tofutsu, and so on. Among them, Kushiro wetland is one of the largest, the coastal area is highly developed, and the population is about 230,000. The main river flowing thought Kushiro wetland is Kushiro River whose river length is 154 km and river basin area is 2510 km^2 (Fig. 1).

Therefore, Kushiro wetland is considered one of the most suitable areas to investigate the effect of sea level rise on flood events. Since Kushiro wetland is revealed to have important ecological system, this study also aims to understand the influence of sea level rise on ecosystem.

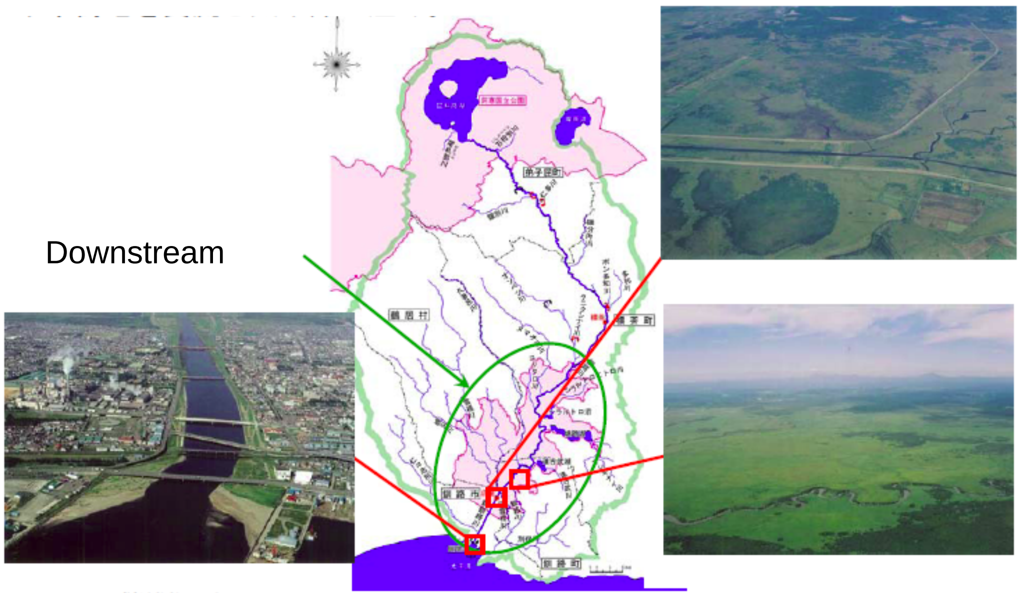

Fig. 1: Kushiro river basin and the Kushiro wetland

2. SIGNIFICANCE

The river mouth area has been developed in Kushiro wetland and the population has become up to 230,000 which may cause big damage when inundation occurs due to flood. Since wetland play a great role in ecological system, rest of the nature has to be protected. From the both points of view, if the sea level rises, flood events would cause serious damages on the developed areas and the ecological system in Kushiro wetland. Therefore, it is needed to investigate the effect of sea level rise in the wetland.

Regarding scientific contribution, there are so many questions left in the wetland which have to be solved urgently, like water circulation, mass transport, morpho-dynamics and so on. The purpose of this study is thus to understand the impact of sea level rise on ecological system.

3. CONCEPT DETAILS

To investigate the influence of flood events when sea level rises, a simple distributed hydrological model will be made or IIS-DHM will be applied. All the necessary data would be available through the Ministry of Land and Infrastructure.

As a next step, the model will be modified in order to include water circulation and mass transport which are important to clarify ecological system. As estuary is the area where fresh water and salt water are mixed, it is necessary to implement stratification effect in the model.

Finally, we make an attempt to model ecological system in Kushiro wetland and to see what happens when sea level rises. In the analysis, we focus on only a few components which control ecological system in Kushiro wetland dominantly to make the problem be solved easier.

4. POTENTIAL OUTCOMES

The following outcomes are expected in this study:

a. The effect of sea level rise on inundated area
b. Development of ecological model in wetland
c. Understanding of water circulation and mass transport in wetland

REFERENCE

Plan of Kushiro River, Hokkaido Development Bureau, 2007.

Dutta, D. and K. Nakayama, Impacts of Spatial data resolution in River flow Simulation by Physically Based Distributed Modeling Approach: A Case Study in Tsurumi River Basin, Japan, Hydrological Processes, accepted, 2007.

Nakayama K. and D. Dutta, Effects of Spatial Grid Resolution on River Flow by the Physically Based Distributed Modeling Approach, Asia Pacific Associationf of Hydrology and Water Resouces (APHW 2006), ST1-01-A03-068, 2006.

Floods in Colombo, Sri Lanka: A Future Scenario

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1. INTRODUCTION & BACKGROUND

Climate change has clearly affected the weather pattern of Sri Lanka and this is evident in the climatological measurements of the last 3 - 4 decades. Overall rainfall has not shown a significant change in most of the places in the country while some other indicators such as the length of the rainy spells, average rainfall per spell has clearly changed and the studies show that the rainfall intensity has increased (Herath and Ratnayake, *2004*; Ratnayake and Herath 2004). More frequent rainfall induced disasters such as landslides, floods and droughts in the recent past can be attributed to this increase in the rainfall (Padma Kumara *et al. 2005*).

Colombo, the capital city and financial hub of Sri Lanka is one of the major costal cities adversely affected by the floods. Colombo received two occurrences of its record highest rainfalls in the last two decades. Such frequent extreme events have focused the attention of the public and have forced the authorities to attempt mitigating works. Several drawbacks of the system have been identified and among the technical aspects the inadequate capacities of the drainage networks, loss of flood retention spaces and poor management is highlighted.

In the previous study Matara city situated close the southernmost point of the country was selected. The study simulated correctly the flood propagation under various scenarios of sea water level rise up. However, flood plains being located at higher elevations produced low sensitivity to sea level rise. It is recognized during the study that low laying flood plains will be greatly affected. (Ratnayake *et al. 2005*; Dutta *et al.*, 2005).

2. SIGNIFICANCE AND OBJECTIVES

The Colombo floods Causes heavy economic losses are mainly due to two reasons. The poor drainage facilities available with their inadequate drainage capacities are the main reason of floods when heavy rains occur in the city area. The other reason is the overflowing of the Kelani River which is flowing through the Northern parts of the city.

The depth reading of the gauge near sea outfall is used to classify the floods. The depths above 0.6m are classified as major floods with economic damages. The climate change scenarios expect sea level rise nearly 1m and with such effects it is clear that part of the city is permanently inundated and the floods in the other parts of the city will be much higher due to reduction in drainage capacity resulting from back water effect. This research will look into the various scenarios of climate change and it will assess the flood extents that will result in such events. The result will help in analysis of future impact assessments and thereby to develop a policy to mitigate the adverse impacts.

Salinity intrusion to the river during dry period is a major issue that needed to be assessed. However, presently a barrage is being constructed to control salinity intrusion. (Herath and Ratnayake *2006*)

3. METHODOLOGY & IMPLEMENTATION PLAN

The Kelani river flows are monitors at several places in the catchments. The main two gauges important in the one close to the sea outfall and located within the city and the other located about 20km upstream. The river flow measured in the upstream gauge and the local inflows downstream will be the inputs to the model. Gauging station located closer to sea outfall will be used to verify the Process Model and the values will be used to classify the floods as it is done currently. It should be noted that the stage reading at this location cannot be converted to discharge reading as the tidal effects are influencing the water flow.

The necessary data required for the models as described in the background paper by Dutta et al. (2007) will be collected through the reputable agencies. Wherever possible the data will be collected from the original sources.

Depending on the model capabilities and availability of the data the study area will be selected. Care will be taken to include most vulnerable areas that frequently affected by the floods due to river overflows or drainage problems. The boundary conditions will be calculated based on the current measurements referred to the study boundaries.

4. POTENTIAL OUTCOMES

It is accepted that climate change will cause the sea level rise. The public and also some policy makers are not aware of the magnitude of possible consequences or they do not like to believe in the possible adverse effects. One out come is to make the public and policy makers aware of this impending problem and to give them an idea on the magnitude of the possible effects. Also, the outcome will identify what policy measures are to be taken, what structural measures are needed and how much can be controlled from the non-structural measures.

REFERENCE

Dutta, D., M.S. Babel and A. Das Gupta (2005). An Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas, Final Report for APN CAPaBLE Project: 2004-CB01NSY-Dutta, Asian Institute of Technology, ISBN 974-93908-0-6, 205 pages.

Herath, G. and U. Ratnayake (2006); "Water Quality Issues in Lower Kelani Basin", Proceedings, International Conference on Water in the Humid Tropics, December 4 2006, Kandy, Sri Lanka

Herath, S. and U. Ratnayake (2004) "Monitoring Rainfall Trends to Predict Adverse Impacts – a Case Study from Sri Lanka (1964-1993)", Journal of Global Environmental Change, Vol. 14, Supplement 1, pp 71 -79

Padma Kumara, N.I., U. Ratnayake, and A.G.H.J. Edirisinghe (2005) "Application of GIS for Landslide Mitigation Works in Sri Lanka", Proceedings, International conference on Monitoring, Prediction and Mitigation of Water-Related Disasters, Kyoto, Japan, pp 47-52.

Ratnayake, U. R. and HERATH, G.B.B. (2004) "Recent Changes in Water Cycle and its Effect on Natural disasters and Eco Systems of Sri Lanka", Proceedings, "Preparatory workshop on Sri Lanka national water development report", for UN-WWAP, 29-30 October 2004, Wattala, Sri Lanka

Ratnayake, U, D. Dutta and S. Niu (2005), "Impacts of Floods Under Sea Level Rising Scenarios in Matara, Sri Lanka", Proceedings, International Symposium on Floods in Coastal Cities Under Climate Change Conditions, Asian Institute of Technology, Bangkok Thailand..

Global Climate Change Impacts at Nam Dinh Coast, Vietnam

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1. INTRODUCTION & BACKGROUND

Nam Dinh coast is one of the most populated coasts in Vietnam. It has the most fertile soil in Vietnam, very suitable for rice cultivation. The coast is also suitable for other marine related economic activities such as salt production, fishing, shrimp and fish farming etc. Additionally, the coast is located near Hanoi, the Capital City of Vietnam and some beaches in the area now become recreation beach for Nam Dinh and Hanoi City dwellers.

The Nam Dinh coast is formatted by the deposition of sediment from the Red River with its four branches, the main river, the Ninh Co River, the Day River and the So river. The sediment from the river is mainly silt and fine sand. Thus, near the river mouth, deposition of silt and fine sand enables the development of mangrove forests. There are very wide mangrove forests in the areas, such as the Giao Thuy mangrove forest, the Nghia Hung mangrove forest. There are several ecological systems in the area such as the marine ecological system, the mangrove forest ecological system and the estuarine ecological system. Thus, the coast has a very diverse ecological system.

Recently, with economic development, a port is constructed at the Ninh Co river estuary. Also, some industrial bases, such as ship building, thermal power station etc. are being constructed.

At present, the coast is facing serious environmental problems. The first problem is erosion. Recently, the coastal erosion is accelerated. At the place with most serious erosion, the coast has been retreated for about 2km. Thus, many local people have to evacuated inland. During the typhoon Damry of September 27, 2005, many segments of the sea dike were broken up due to storm surge in combining with high waves, causing flooding at many places. At the Thinh Long recreation beach, high waves together with storm surge damaged many shops, houses and the road along the coast. This is a densely populated area with high economic activities, and the natural hazard causes large economic losses.

One of other environmental problems at the coast is the degradation of mangrove forests due to shrimp, fish and crab farming. Except the protected mangrove forest at Giao Thuy, almost all mangrove forests at other places are damages to give the land for shrimp, cram and fish farming. Also, the overfishing near the coast and pollution from aquaculture and agriculture damage much the ecological system in the area.

To protect the land from the sea, the Government of Vietnam has spent great efforts to construct dikes and revetment along the whole coast. Since the budget is not sufficient, the dikes are not constructed to withstand the powerful typhoon. Also, the construction of revetment at the foreshore leads to the lowering of beach, making the coastal erosion problems more serious.

Since the area is a very low land area, and at the present, can be inundated during spring tide, a small sea level rise, for example, 50cm, can have great consequence to the coastal erosion, flood inundation, aquaculture, salinity intrusion, agriculture etc. It is certain that within a very short time, the economy of the area will be developed to a much higher level. Thus, it increases the vulnerability of the coastal areas to natural hazards, such as typhoon, flood etc. Sea level rise could have drastic consequences for the livelihoods and socio-economic well-being of the inhabitants of these areas. It is likely that valuable arable land would be lost. Shrimp and crab farms may have to be relocated and coastal fisheries might disappear. The biophysical characteristics of neighbouring regions not permanently inundated by sea water could be affected and this may render these areas unsuitable for agriculture. For example, the irrigation of paddy rice may be seriously affected as a result of the increased intrusion of saline or brackish water. Primary computational results show that if the sea level rise about 50cm, during winter, all three districts: Hai Hau, Giao Thuy, Xuan Truong and a part of Truc Ninh district will have no fresh water for irrigation during dry season. Estuarine and riverine areas could be affected by changes in the tidal regime and in river currents. Vietnam's rich diversity of coastal flora and fauna might be substantially reduced and unique habitats may disappear. Mangrove and cajuput forests - important ecosystems in low-lying areas - may be reduced in extent or lost completely. Marshy areas in river estuaries, habitats and resting places for birds, will be threatened by sea level rise. Likewise, sandy beaches, the place for sea turtles to lay eggs, may be flooded. Observations also indicate that increasing salt intrusion is causing a gradual change in species distribution in the mangrove forests. The more that the mangrove forest area is reduced, the greater the impact from salt water intrusion and erosion on the neighbouring land and the greater the vulnerability of the coastal zone to storm-induced flooding. The social and economic consequences of sea level rise could well be wide-ranging. Port facilities may have to be re-engineered. Coastal industries and agriculture, aquaculture may be lost. Transportation will be disrupted. The provision of drinking water may be affected as saline water may pollute aquifers. Communities living in coastal areas vulnerable to increased flooding need relocated. This would increase pressure on the remaining land. Biodiversity would then be degraded; land erosion increase and flooding worsen as a result.

Results of the study by Nguyen Ngoc Huan [10] show that the flood due to sea level rise may cause great social, economic and environmental damage to the area.

In response to the impact of sea level rise, increased expenditure will be necessary on flood protection and the planning and zoning of activities in coastal areas, including agriculture, industry, transportation and tourism, may have to be rethought. The erosion and flooding in the coastal areas will be more serious. Thus, the construction and maintenance of sea dike to stand against storm surge in combination with high tide will be more difficult.

Therefore, study for the evaluation of the impacts of sea level rise on socio-economic development and environment in the area and propose mitigation and adaptation measures to minimize the impacts are very important to Vietnam.

2. SIGNIFICANCE AND OBJECTTIVES

Even the economic production in the area is not a very large value, the area is very densely populated. Then, a loss of land may cause very serious social problems since there is no land for relocation. Then, it is necessary to find a solution to protect the coast, and mitigate the consequences of climate change to the area.

At present, there are some researches on the effects of sea level rise due to climate change. The most comprehensive study is that of Nguyen Ngoc Huan et al (1996). However, in the study, only economic and social problems relating to flooding are addressed. Other studies (Pham Van Ninh et al, 2006; Pham Quang Son, 2006; Vu Thanh Ca et al, 2007; Delft Hydraulics, 2006) studied the problem of coastal erosion in Nam Dinh. The ecological system in the mangrove forests of Vietnam has been studied before. However, the impacts of sea level rise on the mangrove forest and ecological system are still not considered.

The objective of the study is to understand and quantify the problem of sea level rise due to climate change in Nam Dinh coast, its possible impacts on society, economy, natural and social environment of the coastal areas, and propose adaptation and mitigation measures to minimize possible damages for sustainable socio-economic development. In details, the objectives of the study are:

- Increase the knowledge on the methods of dealing with natural hazards due to climate change and the problem of sea level rise;
- The benefit of local residents in the coastal areas, many of them belongs to the poorest and most vulnerable to natural hazards;
- To prepare for the government to reasonably utilize the resources of the coastal zone for economic and social development while protect the natural and social environment of the area;
- To protect society and various economic sectors in the coastal areas from adverse impacts of sea level rise.

3. CONCEPT DETAILS

To conduct the study, various methods will be used, including field survey, numerical modeling, hazard mapping using GIS technique.

- Field survey: to collect social an economic data
- Numerical model for storm surge, forecast of waves in the open sea and nearshore wave transformation, nearshore current, sediment transport and bottom topography change, salinity intrusion in the estuary, flood inundation, model for the evaluation of the impacts of mangrove forest and ecological system in the mangrove forest, estuary and nearshore areas, models for the evaluation of etc.;
- Necessary data for the models: topography, geology, sediment load from rivers, river discharge, population distribution, economic activity distribution, terrestrial and aquatic ecological system etc.;
- Vulnerability evaluation;
- hazard mapping using GIS technique.

4. POTENTIAL OUTCOMES

- Data base on the sea level rise scenarios, impacts of sea level rise etc.
- Relevant software for analysis and study the sea level rise scenarios, the impacts of sea level rise, the vulnerability of the coastal area, possible adaptation measures etc.,
- Synthesized report developed on the degree of sea level rise and its impacts, and specific measures to maximize the adaptation of the society, various economic sectors, natural and social environment of the coastal areas to the problem of sea level rise;
- Recommendations for the inclusion of sea level rise issue in policies, land and environmental planning, design of infrastructure;
- Enhance the capacity, including personal and knowledge of The Vietnam Institute of Meteorology, Hydrology and Environment, Ministry of Natural Resources of Vietnam and other relevant institutions/organizations on dealing with problems relating to sea level rise and other kinds of natural disasters

REFERENCE

Delft Hydraulics (2006) Vietnam - Netherlands Integrated Coastal Zone Management Project. Project document.

Mazda Y., Magi M., Nanao H., Kogo M., Miyagi T., Kanazawa N., and Kobashi D., (2002) Coastal erosion due to long-term human impact on mangrove forests, Biomedical and Life Sciences and Earth and Environmental Science, Vol. 10, No. 1, 1-9.

Nguyen Ngoc Huan, G. Tom, Frederic Harris, F.J.M Hoozemans, R.B Zeidler (1996) : Vietnam Coastal Zone Vulnerability Assessment.

Pham Van Ninh, Đo Ngoc Quynh, Nguyen Manh Hung, Đinh Van Manh, Nguyen Thi Viet Lien (2006) Some research results on the sediment dynamics and shore line evolution at Nam Dinh coast. Proc. Natural Disaster Prevention, Nam Dinh, May, 2006.

Pham Quang Son (2006) Evolution of esturies and beach at Nam Dinh coast. Proc. Natural Disaster Prevention, Nam Dinh, May, 2006.

Vu Thanh Ca, Tran Thuc, Tran Hong Thai, Nguyen Quoc Trinh (2007) Study the coastal erosion at Nam Dinh Beach. Proc. Sci. Conf. IMH, 4.2007, 56-65.

Vu Thanh Ca (2007) Possible impacts of sea level rise on coastal erosion and flooding in Vietnamese coast. Paper presents at scientific seminar at IMH, Hanoi, April, 2007, 7 pp.

SUMMARY OF SESSION 1

Session 1: Introductory Session
Facilitator: W. Wright

The purposes of the session were: to allow participants to get to know one another well; and to provide a shared broad understanding of the project.

Welcome and overview of project objectives and planned activities

- Dr. Dushmanta Dutta (Project Leader, Australia) presented:
  "Context and Overview of the Project and Objectives of the Planning Workshop"
  Dr. Dutta provided participants with the background to the project; and described the project objectives, project framework, planned activities, expected outcomes and the timeline for the project.
  In addition, Dr. Dutta outlined the objectives and the program for the two day planning workshop.
  The presentation also included Dr. Dutta's perspective of the project

Presentation by remaining participants on individual perspectives on the project

- Prof. Samuel Adeloju (Chief Investigator, Australia) presented his perspective of the project:
  "Title of presentation"
- Dr Wendy Wright (Chief Investigator, Australia) presented her perspective of the project:
  "Impacts of climate perturbations on ecosystems & ecosystem processes"
- Dr Hemanta Doloi (Chief Investigator, Australia) presented his perspective of the project:
  "Selection of optimal strategies for sustainable management using Multi-criteria Decision Making (MDCM) approach"
- Prof Mafizur Rahman (Collaborator, Bangladesh) presented his perspective of the project:
  "Integrated Approaches and Tools for Vulnerability Assessment and Sustainable Management Strategy for coastal zone of Bangladesh"
- Prof Keisuke Nakayama (Collaborator, Japan) presented his perspective of the project:
  "Integrated ecological model"
- Dr Uditha Ratnayake (Collaborator, Sri Lanka) presented his perspective of the project:
  "Perturbation and Coastal Zone Systems in Asia Pacific Region: Holistic Approaches and Tools for Vulnerability Assessment and Sustainable Management Strategy – Case Study: Sri Lanka"
- Dr. Vu Thanh Ca (Collaborator, Vietnam) presented his perspective of the project (presentation co-authored by Prof Tran Truc):
  "Global Climate Change Impacts at Nam Dinh Coast, Vietnam"

- Dr Dhirendra Thakur (Collaborator, Thailand) gave an informal presentation of his perspective of the project

There was substantial discussion between participants during question time at the end of each presentation. Conclusions from discussions during this session are:

- The session provided a good opportunity for participants to get to know one another and to begin to develop a shared understanding of the project and its direction
- Participants concluded that there is a need to set tighter focus for various aspects of the project (objective for sessions on second day):
    - Scope
        - e.g., Bangladesh has set national issues from a previous project - we could choose to follow this scope, or modify it?
        - e.g., Thai fisheries authority has identified areas of concern - can we use these to help us define scope/focus of the project)
        - Scope must be set for each case study area
    - Geographical extent
        - e.g. Thailand case study location needs to be limited to either the Bangkok area of the Chao Phraya delta; or further upstream – but not both
    - Temporal extent (which years for data collection)
    - For environmental aspects of the project, perhaps choose only 1-2 important aspects of environment/ecosystem to include in the model
- One of the important outcomes of this project will be the method used to develop the model.

SUMMARY OF SESSION 2

Session 2: Case Study Areas and Past Related Studies
Facilitator: D. Dutta

In this session, brief overviews of the case study areas in the six participating countries were presented. The presentations included socio-economic and environmental characteristics of the study areas, relevance/importance of the study area to the aims of the project and the related past and on-going projects in those areas. The presenters for different countries were: Australia- S. Adeloju; Bangladesh- M. Rahman; Japan- K. Nakayama; Sri Lanka- U. Ratnayake; Thailand- D. Thakur; and Vietnam- V. T. Ca. The main points of the presentations are summarized below.

Country	Characteristics	Issues	Past & ongoing related studies
Australia *Lakes Entrance area*	Large lakes and major rivers Historically important for coastal shipping (not currently) Important recreational fishery Economic Environmental Cultural Sparse population Ramsar wetlands	Agricultural pollution to lakes (nutrients [N,P] & suspended solids) Water quality Blue green algae Effects of upstream practise (irrigation; land use; fire) Small townships may be affected Damage to wetland ecosystems	GINRF projects CSIRO past studies
Bangladesh *Chittagonj area*	Fish farming Land reclamation Coastal farming Salt farming Port & harbour industry Oil & gas Dense population	Land reclamation Shrimp culture Economic Social Salinity	ICZMP ICRD } database NWRD } database
Japan *Kushiro wetland*	Dense population Wetland Ramsar wetlands Fishery industry	Flooding Upstream nutrients / suspended solids Salinity	Some projects in DHM Ecological modelling
Sri Lanka *Colombo*	Capital city (large population) Existing dyke / salinity barrier River is only source of potable water	Flooding & drainage Salinity intrusion (due to sand mining)	UNU (urban flooding)
Thailand *Bangkok, Lower Chao Phraya delta*	Major city (capital) High urban growth Low lying	Flooding, tidal effect Groundwater Fishery Tourism Coastal erosion Salinity and suspended solids	ICZMP by IUCN

Vietnam *Nam Pinh coast*	Densely populated area Rice cultivation Salt mining Shrimp / fish farming Near to Hanoi Recreational beach Close to a Ramsar site	Erosion Flooding (storm surge) Degradation of mangrove forest Water quality impact on ecology	Coastal vulnerability study (Dutch) (scenario of 1m sea level rise) ICZMP Coastal erosion

SUMMARY OF SESSION 3

Session 3: Country based outcomes of the PRG Meetings
Facilitator: H. Doloi

Important Issues	**Impacts** (S, E, Ev)	**Availability of data** People, Organisations, Databases	**Action required/ expectations**
Australia Flood regime - Time - Frequency - Depth - Width, - Variability, - Resilience and threshold. Salinity - Environmental effects - Fluctuation of salt waters - Frequency of oscillations Env/Bio-dervisity - Algal bloom - Which impacts become the driver of other areas of problems etc.	-Townships -Geological significance -New housing development -Infrastructure damage -Thresholds -Ground water -Salinity intrusions -Porosity of soil -Potable water sources -Mix of salt and fresh water -Health issues -Fish habitat -Distribution of fish species	-CMAs -Gippsland lakes' task force -Gippsland coastal board -EPA etc. etc. Comments: Data sources are known and will be easy to get data as required – SA	-Linkage of various countries study areas and outcomes -Physical and biological issues Not quite clear and to be advised - WW
Bangladesh Reference to the previous presentations	Reference to the previous presentations	-Different ministries -CEGIS -ICZMP -Bangladesh Water Development Board -BMD -Chillogong City Admin	-Integrated coastal zone management database -Data viewing tools -Navigation tools -Quick access to data -Improve the knowledge base -Knowledge communications -Coastal zone management systems COZIS -Resources assessment tools -Expert tools -Mapping tools -Response plans -Cyclone shelters -Communication between Govt. and Public in implementing

			response plans -Transport systems -Management of vulnerable areas -Water supply & proper sanitation systems during inundations
Japan - Suspended solid - Salinity - Flood Inundation - Bio-diversity	-Tourism industry -Building -Roads -Environmental -Social?? (to be advised)	- Ministry of Land and Infrastructure -Outcomes of the ongoing projects -Local Governments	-Policy & direction -Making the city area safe
SriLanka - Flood - Evaluation of impacts - Sediments - Salinity - Water quality	-Relocation of built-up areas -Flood zoning -Provision of any structures -Social issues ?? (TBA) -Environmental issues (TRA)	- Ministry of water resources development -Disaster mitigation center -Irrigation -Dept. of Survey	- Storage of flood water in built up areas -Consequences of extreme conditions -Policy developments
Vietnam - Coastal erosion - Flood during storm and dyke failure - Salinity intrusions - Increased sea level - Mangrove forest/deforestations - Change in biodiversity - Overfishing - Over exploitation of natural resources - Conflict between aquaculture and agriculture - Frequency of flooding - Agriculture production loss	-Loss of crops -Contamination of land -Coastal erosion (social issues) -Relocation of people -Permanent loss of livelihood	-Dept of Environment Conservation Agencies -Own institute -2 ongoing projects -Research of Coastal Erosion -IMH	-Capacity building -Policy making -Sale of data - Expectations??? (TBA from PRGs)
Thailand - Urbanization - Industrialization - Underground water usage - Household waste - Conflicts for	-Increased population density -coastal pollution - Solid waste - liquid waste	To be discussed with the PRG??	To be discussed with PRG??

resource use - Floating market management measure - Sea water intrusion - Air pollution (Urban heat scenarios) - Induced disease/epidemic (eq. insects, plankton) - Water quality - Salt intrusion - Tourists - population density - conflicts (stakeholders & communities) - health - education/ info - livelihoods (activities, sources of income) - property rights plus land right - sectoral groups/ interests - economic value of area/loss - cultural/ traditions - Spatial & Temporal Focus - Chao Praya River & Upper Gulf -10 years	- Immigration - Labor -Agricultural vs Aquaculture, water usage / waste, transportation (Navigation &waste) -Factory density, machine & fuel consumption -Incidence of disease by seasonality -Waste water discharge -Vehicle (SAL) (waste & type & engines -Waste of active groundwater, wells, depth, water consumption - BOD, nitrogen, phosphorus, heavy metals, temperature, pH - Pathogenic -Salinity Level -Coastal pollution		

SUMMARY OF SESSION 4

Session 4: Brainstorming Session
Facilitator: S. Adeloju

1. Commonality of stakeholders views and case study areas in different countries
(Brainstorming, led by S. Adeloju)

The purpose of this session was to identify common areas of interest within the selected case study areas in the six countries represented in this project. The identified common interests within these countries that will thus serve as the focus of this project are identified below.

Environmental	**Economic**	**Social**	**Other**
Salinity	Tourism	Potable water	D.O.
Nutrients (P&N)	Land use planning	Land rights	Aquaculture
Suspended solids (sediment)	Drainage & Infrastructure	Flooding	
Solids (sediments)	Fishery	Population issues (short & long term) (displacement/resettlement)	
Wetland health	Agriculture	Fishery	
Fishery (habitat and population)	Erosion	Building	
		Erosion	

2. On project framework (D. Dutta)

The key identified issues and parameters with respect the project framework are:

- Prediction: to be made for 2025, 2050, 2075,2100 (at 25 years interval)
- Development of tools (physical process model, TBL, LCA modelling)
- 5 Phases:
  - Planning
  - Data & info collation
  - Development of Integrated Assessment Tool
  - Scenario analysis
  - Recommendations and reporting
- Public release of whole tool at end of project (Oct 09)
- Physical model (flood): release to group in Nov 07
- Water quality model (nutrient, salinity, sediment): release Jul/Aug 08 & initial trial in Australia

3. Modeling components (D. Dutta)

Discussion on required modeling components include:

- Draft table presented: this will form the basis of a questionnaire to allow stakeholders to estimate likely impact for each issue under "high", "medium" and "low" values for each variable
  - Will be used to derive TBL damage functions for each issue
  - Draft table to be modified by DD: nutrient variables to include: ortho-P; Total P; Total N; NO_3^-

    - Final version of table to be developed by DD, WW & HD and circulated to other participants shortly after the meeting; as part of the draft proceedings of the meeting
- Impact analysis tool to be developed within next 3 months (establish qualitative & quantitative criteria; indicators & response functions)
- How to identify & prioritise TBL sustainability indicators
- Environmental values of utilities and others: differences in different countries

<u>4. Implementation strategy and timeline (H. Doloi)</u>

Extensive discussion was made on the implementation strategy and timeline particularly:

- Discussion regarding MCDM and data gathering for this aspect of the project
    - Decision to include second part to questionnaire in order to allow stakeholders to provide relative rankings for importance of different variables; and to provide relative rankings for preferred strategies
    - Draft table to form the basis of this second part of the questionnaire was presented and discussed – to be finalised in a later session.

SUMMARY OF SESSION 5

Session 5: Planning of Data Collection Activities
Facilitator: U. Ratnayake

D. Dutta explained about the data requirement for the flood model. The following deadlines were agreed upon

- Release of the flood model - Nov 2007
- Completion of the data collection on selected flood events - Dec 2007
- Submitting preliminary flood modelling results to Monash - Feb 2007
- Completion of the data collection on Nutrients (NOx-, TP, PO4-, Salinity, Suspended sediments) - Dec 2007

W. Wright explained about the data requirement for the impact assessment.

For Wetland Health we need
# of life forms in vegetation
# of bird species present
integrity of vegetation

For Fish Habitat
?

Need to discuss through e-mail which biological elements will we use as indicators for eg. wetland health; fish habitat

H. Doloi discussed in length what data are required for MCDM analysis.

More on data requirements and availability will be discussed through e-mail

SUMMARY OF SESSION 6

Session 6: Planning of Integrated Assessment Tool Development
Facilitator: Keisuke Nakayama

1. A format of the sheet which is used in the application of MCDM analysis was decided with agreements of all participants.

2. Strategies are categorized into six components as follows.
   (1) No intervention required (Do nothing)
   (2) Investment in structural measures
   (3) Investment in non-structural measures
   (4) Capacity building (Individual, institutional, community, organization, investment of R&D)
   (5) Effective implementation of existing policy
   (6) New policy

3. Development of integrated assessment tools are confirmed again.

Appendix 1: Workshop Program

Planning Workshop of the APN Project ARCP2007-14NMY
27-28 September 2007

Venue:
Rama Gardens Hotel
Bangkok, Thailand

Day 0 (Wednesday, 26 September)
- Arrival of the participants in Bangkok

Day 1 (Thursday, 27 September)
9:00-11:00: Introductory Session (Facilitator: W. Wright)
- Welcome and overview of project objectives and planned activities (D. Dutta)
- Presentation by all participants on individual perspectives on the project

Coffee break (11:00-11:30)

11:30-12:30: Case Study areas and past related studies (Facilitator: D. Dutta)
  - Australia (S. Adeloju)
  - Bangladesh (M. Rahman)
  - Japan (K. Nakayama)
  - Sri Lanka (U. Ratnayake)
  - Thailand (D. Thakur/D. Dutta)
  - Vietnam (V. T. Ca)

(Presentation on the Case study areas should include at least: a brief overview of the area including socio-economic and environmental characteristics, relevance/importance to the project, past related studies and outcomes)

Lunch Break (12:30-13:30)

13:30-15:30: Stakeholders response (Facilitator: H. Doloi)
- Outcomes of PRG Meetings in:
  - Australia (W. Wright)
  - Bangladesh (M. Rahman)
  - Japan (K. Nakayama)
  - Sri Lanka (U. Ratnayake)
  - Thailand (D. Thakur)
  - Vietnam (V. T. Ca)

<u>Day 2 (Friday, 28 September)</u>

9:00-11:00: Brainstorming Session (Facilitator: S. Adeloju)

- Commonality of stakeholders views' and case study areas in different countries
- On project framework (D. Dutta)
- Modeling components (D. Dutta)
- Implementation strategy and timeline (H. Doloi)

Coffee break (11:00-11:30)

11:30-12:30: Planning of data collection activities (Facilitator: S. Ratnayake)

- Data for physical modelling (D. Dutta)
- Data for impact assessment tool (W. Wright)
- Data for MCDM analysis (H. Doloi)

Lunch Break (12:30-13:30)

13:30-15:00: Planning of development of integrated assessment tools (Facilitator: K. Nakayama)

Coffee break (15:00-15:30)

15:30-16:30: Final Reporting of the workshop

- brief summary by the facilitator of each session

Appendix B:
List of the Participants

1. Dr. Dushmanta Dutta
Senior Lecturer, School of Applied Sciences and Engineering
Monash University, Gippsland Campus
Churchill, VIC 3842, Australia

2. Dr. Hemanta Doloi
Lecturer, The Faculty of Architecture, Building and Planning
University of Melbourne, Parkville, VIC 3010, Australia

3. Dr. Wendy Wright
Senior Lecturer, School of Applied Sciences and Engineering
Monash University, Gippsland Campus
Churchill, VIC 3842, Australia

4. Dr. Samuel Adeloju
Professor and Head
School of Applied Sciences and Engineering
Monash University, Gippsland Campus
Churchill, VIC 3842, Australia

5. Dr. Mafizur Rahman
Associate Professor, Department of Civil Engineering
Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

6. Prof. Keisuke Nakayama
Professor, Department of Civil Engineering
Kitami Institute of Technology
165 Koen-cho Kitami 090-8507, Hokkaido, Japan

7. Dr. Uditha Rohana Ratnayake
Senior Lecturer, Department of Civil Engineering.
Faculty of Engineering,University of Peradeniya,
Peradeniya 20400, Sri Lanka

8. Dr. Dhirendra Thakur
Researcher
Asian Institute of Technology
Klong Luang, Pathumthani
Thailand

9. Dr. Vu Thanh Ca
Director
Center for Advanced Technology Application Research
Institute of Meteorology and Hydrology
Hanoi, Vietnam

Appendix 3:
Draft Questionnaires

Questionnaire for Development of Response Functions for TBL impact analysis

Background

A set of questionnaire has been designed to obtain feedback from experts and stakeholders to develop a series of response functions to assess the impacts of changes in hydro-biogeochemical processes in coastal zone systems in the context of climate change and anthropogenic forcing on various social, economic and environmental issues (TBL issues) in coastal areas. The hydro-biogeochemical processes include in the questionnaires are restricted only to floods, nutrient, nutrient flux, salinity, and suspended sedimentation.

The various social (s), economic (e) and environmental (ev) issues included are identified after a series of consultations with experts and stakeholders from six different countries of Asia and Pacific region.

Guidelines

The questionnaire has three sections.

Section 1: Background Information
The purpose of this section is to obtain some generic background information from respondents to use in comprehensive analysis of outcomes of the sections 2 & 3.

Section 2: Impacts of Floods
The questionnaire is designed in a tabular format. The table on the page 2 of the questionnaire is designed for obtaining the responder's ranking of impacts of different flood parameters (depth, duration, velocity and frequency) on the issues identified. All the issues are listed in the table and their classification in TBL categories. The magnitude of each flood parameter is presented in categories, low (L), medium (M), and high (H). The magnitude of scale of each of these categories for different flood parameters is defined in the table below. Responders are required to provide their rankings using the ranking score (from 0 to 5) on the grey-color boxes of the table allocated for different issues and flood parameters.

Flood Magnitude Scale

Scale	Depth (m)	Duration (days)	Velocity (m/sec)	Frequency (return period)
Low	<.0.6	< 0.5	0.5	> 20 yrs
Medium	0.6-1.5	0.5-2	0.5 – 1	5-20 yrs
High	>1.5	>2	> 1	< 5 years

Section 2: Impacts of Water Quality (Nutrients, Salinity and Turbidity)

The table 2 on the page 3 of the questionnaire is designed for obtaining the responder's ranking of impacts of different water quality parameters (nutrients, salinity and sedimentation) on the issues identified. All the issues are listed in the table and their classification in TBL categories. The magnitude of each flood parameter is presented in categories, low (L), medium (M), and high (H). The magnitude of scale of each of these categories for different water quality parameters is defined in the table below. Responders are required to provide their rankings using the ranking score (from 0 to 5) on the grey-color boxes of the table allocated for different issues and water quality parameters.

Water Quality Magnitude Scale

Scale	TN (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	TP (mg/L)	PO_4 (mg/L)	Salinity (μ S/cm)	Turbidity (NTU)
Low	<.66	< 0.01	< 50	<.01	< .005	< 30	< 5
Medium	.66-.75	.01 –.05	50-100	.01-.03	.005-.01	30- 100	5-20
High	>.75	> 0.05	> 100	> .03	> .01	> 100	> 20

QUESTIONNAIRE : Page 1/3

Section 1 : Background

The purpose of this section is to obtain some generic background information from respondent to use in comprehensive analysis of outcomes of the sections 2 & 3. Please tick one or more of the options given under each heading.

1. Highest Academic Qualification

- ☐ Undergraduate Diploma
- ☐ BA/BSc
- ☐ MA/MSc/MEng
- ☐ PhD/DSc/Deng
- ☐ Other (please specify) ______________________

2. Area of expertise

- ☐ Civil Engineering
- ☐ Hydrology
- ☐ Water Engineering
- ☐ Social Science
- ☐ Environmental Science
- ☐ Biological Science
- ☐ Chemistry
- ☐ Other (please specify) ______________________

3. Area of Employment

- ☐ Academic
- ☐ Research
- ☐ Private
- ☐ Government
- ☐ Semi-government
- ☐ Other (please specify) ______________________

4. Work Experience

- ☐ < 1 year
- ☐ 1 – 5 Years
- ☐ 5 – 10 Year
- ☐ > 10 Years

QUESTIONNAIRE : Page 2/3

Section 2: Impacts of Floods

Please provide your ranking of impacts (*using the impact ranking score given below the table*) of different flood parameters (depth, duration, velocity and frequency) on different issues listed in the table. For each flood parameters, three categories, low (L), medium (M), and high (H) are used and magnitude scale of each category is defined below the table. The rankings should be provided in the *grey-color boxes of the table below*.

Issues		TBL Class (S/E/Ev)	Ranking of Impacts due to Floods (Water Quantity)											
			Depth			Duration			velocity			Frequency		
			L	M	H	L	M	H	L	M	H	L	M	H
Infra-structure	Drainage	E/S												
	Roads	E/S												
	Railways	E/S												
	Ports & Harbours	E/S												
	Dykes	E/S												
	Coast protection structure	E/S												
	Landuse planning	E/S												
Building	Residential	E/S												
	Non-residential	E/S												
Potable water		E/S												
Water quality		Ev/E/S												
Erosion		E/S												
Tourism		E/S												
Population	Short-term displacement	E/S												
	Long-term resettlement	E/S												
Agriculture		E/S												
Fishery		E/S												
Fish habitat/distribution		Ev												
Wetland health	Extent	Ev												
	Flora biodiversity (no. of veg. species)	Ev												
	Fauna biodiversity (no. of bird species)	Ev												
Mangrove		Ev												

S: Social, E: Economic, Ev: Environment

Impact Ranking Score (Qualitative):

0 Positive impact

1 No/little impact (0-5% damage)
2 Less Impact (5-25% damage)
3 Moderate impact (25-50% damage)
4 High impact (50-75% damage)
5 Extreme impact (75-100% damage)

Flood Magnitude Scale

Scale	Depth (m)	Duration (days)	Velocity (m/s)	Frequency (return period)
Low	<.0.6	< 0.5	0.05	> 20 yrs
Medium	0.6-1.5	0.5-2	0.05 – 0.1	5-20 yrs
High	>1.5	>2	> 0.1	< 5 years

QUESTIONNAIRE: Page 3/3

Section 2: Impacts of Water Quality (Nutrients, Salinity and Turbidity)

Please provide your ranking of impacts (*using the impact ranking score given below the table*) of different flood parameters (depth, duration, velocity and frequency) on different issues listed in the table. For each flood parameters, three categories, low (L), medium (M), and high (H) are used and magnitude scale of each category is defined below the table. The rankings should be provided in the *grey-color boxes of the table below*.

Issues		TBL Class (S/E/Ev)	Ranking of Impacts of changes of Water Quality																				
			Nutrient															Salinity			Turbidity (SS)		
			N			NO_2			NO_3			TP			PO_4								
			L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Infra-structure	Drainage	E/S																					
	Roads	E/S																					
	Railways	E/S																					
	Ports & Harbours	E/S																					
	Dykes	E/S																					
	Coast protection structure	E/S																					
	Landuse planning	E/S																					
Building	Residential	E/S																					
	Non-residential	E/S																					
Potable water		E/S																					
Water quality		Ev/E/S																					
Erosion		E/S																					
Tourism		E/S																					
Popu-lation	Short-term displacement	E/S																					
	Long-term resettlement	E/S																					
Agriculture		E/S																					
Fishery		E/S																					
Fish habitat/distribution		Ev																					
Wetland health	Extent	Ev																					
	Flora biodiversity (no. of veg. species)	Ev																					
	Fauna biodiversity (no. of bird species)	Ev																					
Mangrove		Ev																					

S: Social, E: Economic, Ev: Environment

Water Quality Magnitude Scale

Scale	N (ppm)	NO_2 (ppm)	NO_3 (ppm)	TP (ppm)	PO_4 (ppm)	Salinity	Turbidity
Low							
Medium							
High							

Impact Ranking Score (Qualitative):

0 Positive impact

1 No/little impact (0-5% damage)
2 Less Impact (5-25% damage)
3 Moderate impact (25-50% damage)
4 High impact (50-75% damage)
5 Extreme impact (75-100% damage)