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COMPENDIUM OF DECISION TOOLS TO EVALUATE STRATEGIES FOR ADAPTATION TO CLIMATE CHANGE

Final Report

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CONTENTS

Contributors

This report was funded by the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). This report was prepared by Joel S. Smith, Megan M. Lawson, Stephanie S. Lenhart (Stratus Consulting Inc.), with the assistance of a number of experts including: Ian Burton (Chapter 1), William E. Easterling (Agriculture), Robert Nicholls (Coastal), Jonathan Patz (Health), David Yates (Water). Christina Thomas edited the report. Raeben Sellers, Shiela DeMars, Richard Fyfe, and Sara Garland provided critical support on administration and production. Madiagne Diagne of Senegal, Adriana Marica of Romania, Ahmadul Hassan of Bangladesh, and Richard Warrick of New Zealand reviewed the list of tools to be included in the report and provided helpful suggestions on additional tools to be included.

CHAPTER 1
INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) requires all parties to formulate and implement programs to facilitate adaptation to climate change. By its decision 9/CP.3, the third Conference of the Parties requested the Convention secretariat 'to continue its work on the synthesis and dissemination of information on environmentally sound technologies and know-how conducive to mitigating, and adapting to, climate change; for example by accelerating the development of methodologies for adaptation technologies, in particular decision tools to evaluate alternative adaptation strategies'. A first step is to understand the current use and availability of such decision tools.

This resource compendium describes the wide range of decision tools actively in use across and within different natural resource and socioeconomic sectors. It provides users with key information about available tools, special features of each tool, and information about how to obtain documentation, training, or publications supporting each tool.

Section 1.1 provides the context for this compendium by briefly reviewing how it contributes to the existing state of knowledge on the evaluation of adaptation to climate change. Section 1.2 outlines the focus of the resource compendium, explains how the decision tools were selected, and briefly describes how the compendium was developed. Section 1.3 describes the organization of the compendium.

1.1 BACKGROUND

To date, most of the policy focus on climate change has been devoted to the reduction of greenhouse gas emissions rather than adaptation to the likely change in climate. However, in response to a growing understanding of adaptation as an important response to climate change, many countries have begun identifying, assessing, and in some cases adopting measures to adapt to climate change. In many cases, it is recognized that these adaptations reduce vulnerability to current climate extremes and will help in coping with changes in future climate.

Because of the complexity of making decisions about adaptation, there is a need to develop tools for decision-making that can be employed in the formulation, assessment, and adoption of specific adaptation measures, projects, and programs. This process is now under way, and a new body of knowledge is being built up that to date has been incorporated into four basic reference documents, summarized below.

- Scientific Committee on Problems of the Environment (SCOPE) Report on Climate Impact Assessments
- IPCC Technical Guidelines for Impacts and Adaptation Assessments
- U.S. Country Studies Program Guidebook on Vulnerability and Adaptation Assessments
- UNEP Handbook

The first effort was the SCOPE report (Kates et al., 1985). This edited volume of papers describes climate impacts as they were then understood, in a number of sectors, and focused on socioeconomic impacts and responses. Subsequently the Intergovernmental Panel on Climate Change (IPCC) undertook to develop technical guidelines for assessing impacts and adaptations (Carter et al., 1994; see also Parry and Carter, 1998). The IPCC report lays out a general approach to impacts and adaptation assessment, and in particular proposes seven steps that can be followed in designing research projects.

As valuable as these two documents are in helping to orient researchers and policy analysts, they generally lack specific guidelines or prescriptions. This gap has recently been addressed in connection with two concurrent research programs. The U.S. Country Studies Program, which provided financial and technical assistance to more than 50 developing countries and countries with economies in transition to develop capacity to, among other things, assess vulnerability to climate change and options for adaptation. To assist the countries, a guidebook of methods and approaches was developed. (Benioff et al., 1996). This guidebook provided detailed guidance on a limited set of methodologies, but is intended to be directly applied by researchers.

In the second research program, the United Nations Environment Programme (UNEP) sponsored the writing of a handbook on assessing climate change impacts and adaptation, to serve as a supporting resource for its country studies program. The handbook, produced by the Free University of Amsterdam (Feenstra et al., 1998), presents an overview of different methodologies, covers a number of sectors, and is meant to help program managers select, but not necessarily apply, methodologies.

All four of these products focus more heavily on the impacts of climate change than on the assessment of adaptation options. There is an evident need therefore for a compendium of tools than can be used specifically in the adaptation assessment, selection, and decision process. Adaptation tools need to be able to assess options, which many impact tools cannot do.

This compendium contributes to the current state of knowledge by collecting and summarizing existing decision tools from other sectors, such as economics and engineering. It is intended to contribute to the growing series of helpful documents which decision makers and policy makers can turn to for guidance in developing adaptation strategies.

This compendium focuses on specific evaluation tools that are best applied to examining specific adaptation options such as how to manage coasts to incorporate sea level rise or whether to modify water infrastructure. However, there is need for the development of a broad strategic approach to adaptation at the national level, which will integrate consideration of climate change adaptation with the ongoing processes of national economic and social development. Before assessing specific adaptations, countries may wish to conduct a national level assessment to identify the greatest risks from climate change (see Box 2-1 in Chapter 2). The decision tools described in this compendium are intended to fit into a country's broader social and economic policy objectives. These tools should not be implemented in isolation, but rather in conjunction with a country's overall response to climate change.

This compendium is part of an ongoing process. As the tools described in this compendium are used and field tested, they will be steadily improved and their application to the climate change issue will be refined, making them more relevant and useful. It may be that as a result of this compilation of tools, additional adaptation tools will be identified.

1.2 FOCUS AND SCOPE OF THE COMPENDIUM

The resource compendium has been designed to be used as a reference document to identify available decision tools for evaluating specific adaptation strategies. Note that this is not a manual describing how to implement each tool, but rather a survey of possible tools that can be applied to a broad spectrum of situations. These tools assist users in evaluating characteristics of strategies, such as their economic impact, and cost effectiveness in helping a country to adapt to a particular problem associated with climate change. Each decision tool is described in a summary table that provides information to assist the user in determining:

1. whether the decision tool is appropriate for analyzing adaptation issues of concern
2. whether the tools can be applied given the goals and level of resources available for the adaptation assessment.

The compendium is intended for use by either assessment managers or technical researchers and does not require extensive technical knowledge of modeling or specific decision-making techniques to use. Some of the tools described in the compendium may require particular expertise, but these requirements are described in the summary table.

The resource compendium focuses on decision tools applicable for:

- general analysis (applicable to multiple sectors)
- water resources
- coastal resources
- agricultural resources
- human health resources.

Users interested in evaluating adaptation strategies for specific sectors not listed above (e.g., forestry, biodiversity, energy, human settlements) can refer to the tools applicable for multiple sectors. There are a number of decision tools in that section that can be used to evaluate climate change adaptation strategies in multiple natural resource and socioeconomic sectors.

The decision tools described in this compendium were identified based on review of several guidances on impact and adaptation assessment, e.g., guidances prepared by the U.S. Country Studies Program, the UNEP, and the International Panel on Climate Change (IPCC), experience providing technical assistance to developing countries, and consultation with technical experts. To be included in the compendium, a decision tool had to have:

- the capability to assist users in evaluating:
    1. how alternative adaptation strategies affect biophysical or socioeconomic impacts
    2. tradeoffs among alternative adaptation strategies
- existence of a user group (i.e., individuals that have experience using the tool)
- existence of a user guide or documentation describing the tool
- application at either the regional, national, or local scale.

To obtain input from a broad spectrum of practitioners, a preliminary list of decision tools was circulated for review by over 35 experts in 30 countries, and additional tools were included based on their suggestions. The summary tables were developed in conjunction with climate change adaptation experts and technical experts in each of the sectors.

1.3 ORGANIZATION OF THE COMPENDIUM

Chapter 2 of the compendium contains the summary tables that describe each tool, with those applicable to multiple sectors listed first and the remaining tools organized by sector (water, coastal, agriculture, human health). A list of the tools covered in each sector is provided in Table 1-1.

Table 1-1
Tools Covered in Each Sector

Table Titles (additional models included in table, where applicable)
General Tools
Expert Judgment
Screening of Adaptation Options
Historical or Geographic Analogs: Forecasting by Analogy
Adaptation Decision Matrix (ADM)
Tool for Environmental Assessment and Management (TEAM)
CC:TRAIN/VANDACLIM
Uncertainty and Risk Analysis
Estimating Adaption Costs: M-CACES
Benefit-Cost Analysis
Water Sector
WaterWare
Water Evaluation and Planning System (WEAP)
RiverWare
Interactive River and Aquifer Simulation (IRAS)
Aquarius
Coastal Sector
IPCC Common Methodology
UNEP Handbook Methodology
Decision Support Models (COSMO, CORONA, NATWEST)
The South Pacific Island Methodology (SPIM)
RamCo
Agricultural Sector
International Consortium for Application of Systems Approaches to Agriculture (ICASA) — International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Family of Models
General-Purpose Atmospheric Plant Soil Simulator (GAPS 3.1)
Erosion Productivity Impact Calculator (EPIC)
CROPWAT
Alfalfa 1.4
AFRC-Wheat
RICEMOD
GOSSYM/COMAX
GLYCIM
Econometric (Ricardian-based) Models
Input-Output Modeling (with IMPLAN)
Human Health Sector
MIASMA (Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)
DENSiM (Dengue Simulation Model)

1.4 REFERENCES

Benioff, R., S. Guill, and J. Lee (eds.). 1996. *Vulnerability and Adaptation Assessments: An International Guidebook.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Carter, T.R., M. L. Parry, H. Harasawa, and S. Nishioka (eds.). 1994. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Department of Geography, University College, London.

Fankhauser, S., J. B. Smith and R.S.J. Tol. In Press. "Weathering Climate Change: Some Simple Rules to Guide Adaptation Decisions." *Ecological Economics*.

Feenstra, J., I. Burton, J. Smith, and R. Tol (eds.). 1998. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, version 2.0*. United Nations Environment Programme, Nairobi, and Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

Kates, R. W., J. Ausubel, and Berberian (eds.). 1985. *Climate Impact Assessment. Studies of the Interaction of Climate and Society. Scientific Committee on Problems of the Environment. SCOPE Report No. 27*. John Wiley and Sons, Chichester, United Kingdom.

Parry, M., and T. Carter, *1998. Climate Impact and Adaptation Assessment: A Guide to the IPCC Approach*. Earthscan Publications Ltd., London.

Smith, J.B. 1997. "Setting Priorities for Adapting to Climate Change," *Global Environmental Change*. 7:251-264.

CHAPTER 2
COMPENDIUM OF DECISION TOOLS

This chapter contains the decision tool summary tables. Each table summarizes key features about each tool, with some tables summarizing more than one, to introduce the range of decision tools that are available. Using these tables as a reference, users can decide which tools they may want to implement and then obtain further documentation for the listed contact to fully evaluate each option. Each tool has been summarized to identify its potential applications. Based on the resources available and the individual needs of the project, the user can identify which tools may be most appropriate to analyze the adaptation options they are considering. These tables provide information on the stage when each tool should be used (e.g., initial evaluation, final analysis); the financial, data, and personnel resources required to successfully use each tool; and the questions each tool can (and cannot) answer.

Each summary table is organized by the following topics:

- ***Description.*** Explains the type of tool being presented (e.g., spreadsheet, process-based model) and what type of information this tool helps the user to evaluate (e.g., monetary costs, human health risks). This area also provides a basic summary of how the tool works, including the type of data it requires and the processes used to evaluate these data.
- ***Appropriate use.*** Describes where the tool is (and is not) applicable. This gives the user an idea of the stage at which this tool is appropriate to use.
- ***Scope.*** Covers the fields in which the tool is applicable, including geographic (i.e., whether it is specific to a particular region); and assessment characteristics (e.g., national or site-specific).
- ***Key output.*** Describes the final product of the tool (e.g., a model, a cost-effectiveness evaluation, an organizing framework).
- ***Key input.*** Explains the information or data required to use the tool.
- ***Ease of use.*** Describes the level of difficulty associated with implementing this tool.
- ***Training required.*** Describes the level of expertise and any specific skills required to use the tool effectively.
- ***Training offered.*** Describes the training available to learn how to use the tool effectively.
- ***Computer requirements.*** Describes the computer hardware and software necessary to use the tool.
- ***Documentation.*** Provides the citations for sources describing in detail how to use the tool. Generally this is a user's manual or similar document.
- ***Applications.*** Briefly describes actual cases and projects where this tool has been applied.
- ***Contacts for tools, documentation, and technical assistance.*** Provides information on who to contact for further information, documentation, and technical assistance. Generally the agency or firm that developed the tool, or, for several of the tools applicable to multiple sectors, someone who can provide a reference to an expert for a particular application.
- ***Cost***. Provides the monetary cost of obtaining documentation or software for the tool. Where applicable, provides information on the approximate cost of implementing the tool. In cases where the exact cost is unavailable, relative cost is used (e.g., high, medium, or low relative to other tools described).
- ***References.*** Provides the citations for documents, articles, etc. that have critically discussed use of this tool.

2.1 DECISION TOOLS APPLICABLE TO MULTIPLE SECTORS

The general decision tools described in this compendium, listed in Table 2-1, are applicable to multiple sectors. They provide a general evaluation of adaptation options, are easily adapted to numerous regions and situations, and are generally used in conjunction with sector-specific tools to develop a comprehensive analysis. They fall into three broad categories: initial survey, economic analysis, and general modeling.

The initial survey tools include expert judgment, screening of adaptation options, and the adaptation decision matrix, and are useful for identifying potential adaptation strategies or narrowing down the list of appropriate options. They are generally relatively informal, inexpensive, and utilize qualitative judgment rather than quantitative data.

General tools for economic analysis include financial analysis, benefit-cost analysis, cost-effectiveness analysis, and risk-benefit/uncertainty analysis. These are typically used to determine which options are most economically efficient, and to assist the user in deciding which adaptation option is the most appropriate once a final list of adaptation options has been compiled.

General modeling tools include TEAM and CC:TRAIN. These address different adaptation strategies across a number of sectors, and are generally used to evaluate several sectors of concern in a particular region.

In addition, Box 2-1 describes a "strategic approach addressing adaptation." This could be an appropriate initial step in examining adaptation measures and should be applied before in-depth analyses of specific adaption are done.

Table 2-1
Tools Applicable to Multiple Sectors

Table Titles (additional models included in table, where applicable)
Expert Judgment
Screening of Adaptation Options
Historical or Geographic Analogs: Forecasting by Analogy
Adaptation Decision Matrix (ADM)
Tool for Environmental Assessment and Management (TEAM)
CC: TRAIN/VANDACLIM
Uncertainty and Risk Analysis
Estimating Adaption Costs: M-CACES
Benefit-Cost Analysis

Expert Judgment

Description	Expert judgment is an approach for soliciting informed opinions from individuals with particular expertise. This approach is used to obtain a rapid assessment of the state of knowledge about a particular aspect of climate change. It is frequently used in a panel format, aggregating opinions to cover a broad range of issues regarding a topic. Expert judgment is frequently used to produce position papers on issues requiring policy responses and is integral to most other decision-making tools.
Appropriate Use	This approach is most useful either in conjunction with a full research study or when there is insufficient time to undertake a full study. It is important to be aware, however, of the subjective nature of expert judgment and the need to select a representative sample of experts to cover the full spectrum of opinion on an issue.
Scope	All locations; all sectors; national or site-specific.
Key Output	Current information on any area of climate change and subjective assessment of potential adaptation options.
Key Input	Knowledge of experts' respective areas of expertise.
Ease of Use	Easy to apply.
Training Required	Requires knowledge of policy issues and available experts. More training may be required to assemble an expert panel, formulate questionnaires, and interpret and aggregate expert opinions.
Training Offered	Informal training offered; contact Ian Burton (see below) for information.
Computer Requirements	None.
Documentation	See Appendix for description.
Applications	UK, Mackenzie Basin in Canada, Finland.
Contacts for Tools, Documentation, and Technical Assistance	Referral provided by Ian Burton, Environment Canada, 4905 Dufferin Rd., Downsview, ON, Canada; Tel: +1.416.739.4314; e-mail: Ian.Burton@ec.gc.ca.
Cost	Cost depends on the fee charged by the experts.
References	Smith, J.B. and D.A. Tirpak. 1990. The Potential Effects of Global Climate Change on the United States. Report to Congress, United States Environmental Protection Agency, Washington, D.C. Cohen, S.J. (ed.). 1997. Mackenzie Basin Impact Study. Downsview, Ontario: Environment Canada. No. En 50-118/1997-IE.

Screening of Adaptation Options

Description	This matrix-based decision-making tool sets up a series of criteria that allow the user to narrow the list of appropriate adaptation measures. The user sets up a table with evaluation criteria across the top: will the measure target a high-priority area, will it address targets of opportunity, is it likely to be effective, will it generate other benefits (e.g., economic, environmental), is it inexpensive, and is it feasible. The user can insert or substitute other criteria if they are more appropriate. The user then evaluates each measure against these criteria, entering a simple "yes" or "no" in the cells. This tool is frequently combined with expert judgment.
Appropriate Use	This is a useful tool at the beginning of the decision-making process, allowing the user to create a manageable although possibly subjective list of options, which can then be analyzed more rigorously.
Scope	All locations; all sectors; national or site-specific.
Key Output	A simple matrix, clearly showing the strengths and weaknesses of a wide range of options.
Key Input	Basic summary information about options under consideration.
Training Required	Requires background knowledge of both the options and the climate change issue being addressed.
Training Offered	Contact Stratus Consulting for more information (see below).
Computer Requirements	IBM-compatible 286; Lotus 1-2-3 or Excel spreadsheet software helpful.
Documentation	Benioff, R. and J. Warren (eds.). 1996. Steps in Preparing Climate Change Action Plans: A Handbook. Washington, DC: U.S. Country Studies Program.
Applications	Used by several participants in the U.S. Country Studies and UNEP assistance programs (e.g., Kazakhstan, Cameroon, Uruguay, Bolivia, Antigua and Barbuda).
Contacts for Tools, Documentation, and Technical Assistance	Joel Smith, Stratus Consulting, P.O. Box 4059, Boulder, CO 80306; Tel: +1.303.381.8000; Fax: +1.303.381.8200; e-mail: jsmith@stratusconsulting.com; website: www.stratusconsulting.com.
Cost	No cost to obtain documentation or diskette with template of the decision matrix.
References	Mizina, S.V., J.B. Smith, E. Gossen, K.F. Spiecker, and S.L. Witkowski. In Press. "An Evaluation of Adaptation Options for Climate Change Impacts on Agriculture in Kazakhstan." Mitigation and Adaptation Strategies for Global Climate Change.

Historical or Geographic Analogs: Forecasting by Analogy

Description	This qualitative tool is a method for evaluating the effectiveness of potential adaptation strategies by making comparisons with observed adaptations to past climate extremes in different geographic locations, sectors, or time periods. This method looks at events that have had a similar effect in the recent past to the likely impact of future events associated with climate change, assuming that lessons can be learned from such past experience and then applied to future situations. These compared situations can generally share several important characteristics such as time scale, severity, reversibility, impacted sector, or aggravating factors, and point out how well actual adaptation response worked or did not work.
Appropriate Use	This approach is useful during the initial survey stages of evaluating adaptation strategies to avoid duplicating research or to narrow the list of feasible options, and is generally used in conjunction with a quantitative evaluation of adaptation options. This approach does not provide a method to weigh the trade-offs among different adaptation options, but instead provides insight into how the adaptation process may work. Also, an example of adaptation in one place at a particular time is not always applicable to a future adaptation at a different place.
Scope	All locations; all sectors; national or site-specific.
Key Output	A broad perspective on previous research and attempted strategies used to address similar situations.
Key Input	General information on other adaptation issues: research done, approaches used, problems encountered. Often performed by a multi-disciplinary panel of experts, including relevant members of the research community such as climatologists, meteorologists, hydrologists, entomologists, and epidemiologists.
Ease of Use	Relatively easy to use, although the robustness of the comparison depends on the extent of the user's knowledge of the situations being compared.
Training Required	Requires a background understanding of the adaptation issues being compared.
Training Offered	Contact Michael Glantz for more information (see below).
Computer Requirements	None.
Documentation	Glantz, M., and J. Ausubel. 1998. Impact assessment by analogy: Comparing the impacts of the Ogallala Aquifer depletion and CO2 induced climate change. In Societal Responses to Regional Climate Change: Forecasting by Analogy, M. Glantz, ed., Boulder, CO: Westview Press.
Applications	Used in U.S. EPA-supported project on analogous forecasting of the societal responses to the regional impacts of global warming. Also used to evaluate fisheries in Poland, Mexico, and the Far East.
Contacts for Tools, Documentation, and Technical Assistance	Michael Glantz, University Corporation for Atmospheric Research, P.O. Box 3000, Boulder, CO 80303 USA; Tel: +1.303.497.8117; e-mail: glantz@ucar.edu.
Cost	Low cost to obtain documentation.

Historical or Geographic Analogs: Forecasting by Analogy (cont.)

References	Glantz, Michael (ed.). 1988. Societal Responses to Regional Climatic Change: Forecasting by Analogy. Boulder, CO: Westview Press. **Coastal:** Hands, E.B., 1983. The Great Lakes as a test model for profile responses to sea level changes. In: Komar, P.D.(ed.), CRC Handbook of Coastal Processes and Erosion, CRC Press, Boca Raton, pp.167-189. Mimura, N. and H. Nobuoka, 1995, Verification of the Bruun Rule for the estimation of shoreline retreat caused by sea-level rise. Coastal Dynamics 95, W.R. Dally and R.B. Zeidler (eds.). American Society of Civil Engineers, New York, pp. 607-616. Parkinson, R.W. (Ed.) 1994. Sea-level rise and the fate of tidal wetlands. Journal of Coastal Research, 10: 987-1086. **Health:** FAO. 1998. An El Nino Primer. Rome, FAO (www.fao.org). Jury, M.R. 1996. Malaria Forecasting Project. In: Workshop on Reducing Climate-Related Vulnerability in Southern Africa. Victoria Falls, Zimbabwe, October 1-4, 1996. SADC/NOAA/NASA. Silver Spring, NOAA, OGP.

Adaptation Decision Matrix (ADM)

Appropriate Use	This approach is useful when many important benefits of meeting policy objectives cannot be easily monetized or expressed in a common metric. However, detailed research and analysis are needed to provide a basis for the evaluation; otherwise the scoring may be mainly subjective.
Scope	All locations; all sectors; national or site-specific.
Key Output	Relative cost-effectiveness of alternative adaptation measures.
Key Input	A ranking of how well policy objectives are met using alternative strategies; estimated costs of adaptation measures.
Ease of Use	Relatively easy to apply; more rigorous results require more analysis; only basic computer skills are needed.
Training Required	A user with an understanding of key policy objectives could achieve proficiency in 1 to 2 days; however, additional training may be required to develop skill in estimating costs of adaptation measures.
Training Offered	Contact Stratus Consulting for more information (see below).
Computer Requirements	IBM-compatible 286; Lotus 1-2-3 or Excel spreadsheet software helpful.
Documentation	Benioff, R. and J. Warren (eds.). 1996. Steps in Preparing Climate Change Action Plans: A Handbook. Washington, DC: U.S. Country Studies Program.
Applications	Used by participants in the U.S. Country Studies and UNEP assistance programs (e.g., Kazakhstan, Cameroon, Uruguay, Bolivia, Antigua, and Barbuda).
Contacts for Tools, Documentation, and Technical Assistance	Joel Smith, Stratus Consulting, P.O. Box 4059, Boulder, CO 80306 USA; Tel: +1.303.381.8000; Fax: +1.303.381.8200; e-mail: jsmith@stratusconsulting.com; website: www.stratusconsulting.com.
Cost	No cost for documentation or diskette with template of the decision matrix.
References	Mizina, S.V., J.B. Smith, E. Gossen, K.F. Spiecker, and S.L. Witkowski. In press. An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. Mitigation and Adaptation Strategies for Global Climate Change.

Tool for Environmental Assessment and Management (TEAM)

Description	This software package creates graphs and tables that allow experts to compare the relative strengths of adaptation strategies using both quantitative and qualitative criteria. TEAM assists the user in evaluating issues such as equity, flexibility, and policy coordination. The user lists the strategies across the top of the table and the evaluation criteria down the side, then enters a score indicating the relative performance of each strategy under the various criteria. This table can then be used to construct a variety of graphs of the data. It will not necessarily identify the optimal strategy (unless one strategy outperforms all others in all criteria), but is instead designed to allow the user to more clearly see the strategies' relative strengths and weaknesses.
Appropriate Use	TEAM is useful when it is important to consider a wide range of criteria and to explicitly identify unquantifiable and uncertain aspects associated with potential adaptations. It should be used in conjunction with other decision-making tools (e.g., cost-benefit analysis, discussion and workshops with key decision-makers).
Scope	All locations; covers coastal zones, water resources, agriculture, as well as a general assessment component; national or site-specific.
Key Output	Relative effectiveness of alternative adaptation measures across a range of criteria.
Key Input	A ranking of how well policy objectives are met using alternative strategies.
Ease of Use	Relatively easy to apply; more rigorous results require more analysis; only basic computer skills are needed.
Training Required	A user with an understanding of key policy objectives could achieve proficiency in 1 to 2 days.
Training Offered	Contact Susan Herrod-Julius for more information (see below).
Computer Requirements	IBM-compatible 386 with a 3.5" drive and a mouse; Microsoft Windows 3.1 and Excel 5.0c spreadsheet software.
Documentation	Smith, A., H. Chu, C. Helman. 1996. Tool for Environmental Assessment and Management: Quick Reference Pamphlet. Washington, DC: Decision Focus Incorporated. Smith, A., H. Chu, C. Helman. 1996. Documentation of Tool for Environmental Assessment and Management. Washington, DC: Decision Focus Incorporated.
Applications	Used in China, Costa Rica, Venezuela, Trinidad, Italy, Egypt, and Malawi.
Contacts for Tools, Documentation, and Technical Assistance	Susan Herrod-Julius, EPA Office of Policy, Planning and Evaluation, M-2732, 401 M Street, S.W., Washington, DC 20460 USA; Tel: +1.202.260.6022; Fax: +1.202.260.6405. e-mail: herrod.susan@epa.gov.
Cost	Free to obtain documentation.
References	Burton, I., J. Smith, S. Lenhart. 1998. "Adaptation to Climate Change: Theory and Assessment," in Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies. Feenstra, J., I. Burton, J. Smith, R. Tol (eds.). Amsterdam: United Nations Environment Program.

CC: TRAIN/VANDACLIM

Description	Also known as VANDACLIM, this Windows-based tool walks the user though the main steps required to complete a climate change vulnerability and adaptation assessment. Using either default settings or data entered by the user, this application creates a model of climate change impacts for a selected area. CC:TRAIN is menu-driven, with choices for global temperature change scenarios, regional patterns of climate change, scale patterns by global temperature change, and present climate adjustments by temperature change. This application presents results in both map and chart form. The user can enter default settings and the application will act as a tutorial, walking through a hypothetical vulnerability and adaptation assessment for a fictional country. The user can also enter data on their own site of interest and the application will model climate change impacts, creating a site-specific vulnerability and adaptation assessment.
Appropriate Use	This application is useful for both introducing users to the process of vulnerability and adaptation assessments and modeling the impacts of climate change on biophysical factors and human health. It does not include economic models, but information generated from this application can be used as input for economic models.
Scope	All locations; agriculture, water resources, coastal environment, and human health sectors; national or site-specific.
Key Output	Map- and chart-based models of climate change impacts.
Key Input	Data related to site's land use, climate, economy, and population. No data entry required if using as a tutorial.
Ease of Use	Tutorial function is simple and easy to use. Using application as an analysis/modeling tool requires user to enter site-specific data.
Training Required	Applying CC:TRAIN as an analytical or modeling tool will require background knowledge of the site's geography, land use, climate, economy, and population. Otherwise, only a general understanding of climate change issues is required.
Training Offered	Contact Richard Warrick for references.
Computer Requirements	IBM-compatible; Windows 95 (or a more recent version).
Documentation	http://www.geic.or.jp/cctrain.
Applications	Applied by 10 countries in the Pacific Island Climate Change Assistance Program to help prepare draft vulnerability and adaptation assessments.
Contacts for Tools, Documentation, and Technical Assistance	*Tools and Documentation:* UNITAR, Palais de Nations, CH-1211, Geneva 10, Switzerland; Tel: (41-22)788.1417; Fax: (41-22)733.1383; website: www.geic.or.jp/cctrain. *Technical Assistance:* Richard Warrick, International Global Change Institute, University of Waikato, Private Bag 3105, Hamilton, New Zealand; Tel: 64.7.838.4276; Fax: 67.7.838.4289; e-mail: r.warrick@waikato.ac.nz.
Cost	No cost to obtain documentation or software from the website.
References	Warrick, R.A., Kenny, G.J., Sims, G.C., Ye, W., Sem, G. 1997. VANDACLIM: A Training Tool for Climate Change Vulnerability and Adaptation Assessment. In: J.E. Hay and C. Kaluwin. Climate Change and Sea Level Rise in the South Pacific Region. Waikato, New Zealand: International Global Change Institute. CEARSPub-97-6-VANDACLIM-1.

Uncertainty and Risk Analysis

Description	This approach can be applied through critical review of available literature and data or through data analysis using software programs. Uncertainty and risk analysis allow the user to address the errors and unknowns often associated with data and information used to evaluate climate change adaptation measures. A key element of uncertainty and risk analysis is defining the decision criterion that is most appropriate for the question at hand. Uncertainty and risk can be assessed qualitatively, using probability ratings such as slight, moderate, and high. Uncertainty can also be assessed quantitatively, using decision analysis tools (e.g., decision trees) or sensitivity analyses such as Monte Carlo analysis. This method is often used in conjunction with other assessment techniques.
Appropriate Use	This tool is an important step in any assessment of climate change adaptation measures. Quantitative analyses using decision theory or simulation techniques are most useful when evaluating the data used for benefit-cost or similar quantitative analyses.
Scope	All locations; all sectors; national or site-specific.
Key Output	Depending on the method used, a quantitative or qualitative estimate of the uncertainty or risk associated with data being used to evaluate an adaptation measure.
Key Input	Information and data used for other analyses of an adaptation measure.
Ease of Use	Relatively easy to apply.
Training Required	Requires an understanding of the policy objectives and adaptation measures being considered. Monte Carlo and other quantitative analyses require training in specific techniques and uses of statistical software.
Training Offered	Contact Stratus Consulting for more information (see below).
Computer Requirements	IBM-compatible 286; Lotus 1-2-3 or Excel spreadsheet software; @Risk, Crystal Ball software applications.
Documentation	U.S. Environmental Protection Agency, draft. Guidelines for Preparing Economic Analyses. Washington, D.C.: Environmental Protection Agency.
Applications	Used to help determine total programmatic effectiveness of the Global Environment Facility (GEF).
Contacts for Tools, Documentation, and Technical Assistance	Joel Smith or Brian Hurd, Stratus Consulting, P.O. Box 4059, Boulder, CO 80306 USA; Tel: +1.303.381.8000; Fax: +1.303.381.8200; e-mail: jsmith@stratusconsulting.com, bhurd@stratusconsulting.com; website: www.stratusconsulting.com.
Cost	Documentation is free. Cost of analysis varies depending on type of analysis used; quantitative analyses are more time consuming and costly.
References	Brklacich, M. and B. Smit. 1992. Implications of changes in climatic averages andvariability on food production opportunities in Ontario, Canada. Climatic Change, 20, 1-21.

Estimating Adaptation Costs: M-CACES

Description	M-CACES, a Windows-based software program, is required by the U.S. Army Corps of Engineers for the preparation of water resources construction and rehabilitation cost estimates for projects with Federal costs exceeding $2,000,000. The Unit Price Book associated with M-CACES provides production rates, unit costs, and crew composition for the United States. Price escalation for inflation is utilized to adjust pricing to the project schedule and to fully fund the estimate.
Appropriate Use	Useful for estimating the costs of large natural resources construction projects (including dams, shoreline protection, ecosystem rehabilitation). Best used for final rather than initial cost analyses due to the amount of time and data required to complete.
Scope	Designed for the United States, but can be adapted to other countries; multiple sectors; site-specific
Key Output	Cost estimate for natural resources projects.
Key Input	Quantity Atake-offs@ from drawings, specifications and references.
Ease of Use	Requires extensive data on the costs associated with the project. Relatively easy to apply if data is available; more rigorous results require more analysis.
Training Required	Training is suggested to acquire skill in developing quality cost estimates and customizing databases for site-specific or project specific elements.
Training Offered	Building Systems Design (see below)offers monthly training classes.
Computer Requirements	IBM compatible computer with Microsoft 95 or later operating system.
Documentation	Supplemental construction cost information is published in USA by R.S. Means Company, Inc., Publishers & Consultants, +1.617.585.7880 or Dodge Cost Systems, McGraw Hill Information Systems Company, +1.800.544.2678.
Applications	Used as an internal tool by the US Army Corps of Engineers to estimate construction and rehabilitation costs of water resources projects. Also used by the U.S. Department of Defense, the U.S. Department of Energy, and the U.S. Environmental Protection Agency.
Contacts for Tools, Documentation, and Technical Assistance	*Tools and Documentation:* Roy Braden, Cost Engineering Branch, Headquarters, US Army Corps of Engineers, USA; Tel. +1.202.761.1495; e-mail: Roy.E.Braden@usace.army.mil. *Technical Assistance:* Building Systems Design, Inc., 1175 Peachtree St., 100 Colony Square, Suite 1900, Atlanta, GA 30361 USA; Tel: +1.404.876.4700; Fax: +1.404.876.0006.
Cost	Cost of obtaining and running the model depends on scale of project
References	None available

Benefit-Cost Analysis

Description	This approach uses a conceptual framework for analyzing an adaptation measure by identifying, quantifying, and monetizing the costs and benefits associated with the measure. Spreadsheet software is often used to facilitate analysis; however, the specific approaches used are highly dependent on the measure under consideration. This tool can be used to determine whether the benefits of the adaptation measure outweigh the costs, whether net benefits are maximized, and how the measure compares to other options.
Appropriate Use	A benefit-cost analysis is useful when the adaptation being considered is likely to involve significant expenditures of capital and labor. Benefit-cost analyses of adaptation responses often involve a high degree of uncertainty when quantifying nonmarket goods and services as well as when anticipating the direction and magnitude of climate change.
Scope	All locations; all sectors; national or site-specific.
Key Output	A monetary comparison of the costs and benefits of a proposed adaptation measure.
Key Input	Quantitative values for all significant costs and benefits associated with the proposed response.
Ease of Use	A major undertaking, involving extensive research and economic analysis.
Training Required	Knowledge in economics as well as training in estimating the monetary values of costs and benefits. Knowledge of physical sciences related to benefits.
Training Offered	Contact Stratus Consulting for more information (see below).
Computer Requirements	Lotus 1-2-3 or Excel spreadsheet software helpful.
Documentation	The World Bank. 1991. Environmental Assessment Sourcebook: Volume I-III. World Bank Technical Paper 139, 140, and 154. Washington, DC: The World Bank.
Applications	Used to evaluate sea-level rise adaptation options in Maine, U.S.
Contacts for Tools, Documentation, and Technical Assistance	Bob Raucher, Stratus Consulting, P.O. Box 4059, Boulder, CO 80306 USA; Tel: +1.303.381.8000; Fax: +1.303.381.8200; e-mail: braucher@stratusconsulting.com; website: www.stratusconsulting.com.
Cost	Analysis entails a high cost in terms of time for an economic analyst. Method can be modified if financial constraints prohibit a full scale analysis.
References	Smith, J.B., S.E. Ragland, R.S. Raucher, and I. Burton. 1997. "Assessing Adaptation to Climate Change: Benefit-Cost Analysis." Report to the Global Environment Facility. Boulder, Colorado: Hagler Bailly Services, Inc.

BOX 2-1
A STRATEGIC APPROACH FOR ADDRESSING ADAPTATION

This approach assesses current adaptation programs and measures in the context of a country's economic and social development rather than by separate sectors. This strategic approach is an appropriate first step in the adaptation process, to ensure that current and future policies are addressing the impacts that are potentially most severe. It is based in part on a pilot study in Uganda[a] and includes the following steps:

1. ***Identify and assess present-day climate impacts and stresses.*** To ground the assessment of adaptation options in real experience, the design of a climate change adaptation strategy should begin with a careful study of the impacts and stresses of present-day climate to provide a baseline set of measurements and observations that can be used to measure progress toward reducing vulnerability to climate change.

2. ***Determine which current climate impacts and stresses are likely to become more severe under conditions of future climate change.*** Expert judgment is used to compare present impacts with the results of studies predicting future impacts under different climate change scenarios. This comparison allows users to determine which impacts will be the most severe.

3. ***Assess current policies and practices for adaptation to current climate.*** Next, the effectiveness of existing policies and practices for adaptation to climate change must be assessed. Rather than addressing all of a country's policies at once, to make this task more manageable, the assessment should proceed by sector and focus on policies addressing the most severe impacts identified in step 2. The analysis should be careful to include policies such as taxes, subsidies, and trade policies that may have indirect impacts on a country's capacity for adaptation to climate change. These sectoral analyses can then be aggregated to form a country-level perspective.

4. ***Hold a workshop to select policies.*** Because adaptation measures in one sector can reinforce or conflict with measures in another sector, coordination between sectors is advisable at an early stage before projects and plans become too advanced. Organizing these sectoral adaptation measures will then provide the means for creating a coordinated, cross-sectoral, national policy agenda. This can be achieved by holding an adaptation strategy and policy workshop for policymakers from different affected sectors to discuss adaptation needs and strategies that should be pursued in multiple sectors. The workshop should set priorities by selecting adaptation measures that address the areas of highest risk and appear to have the greatest chance for reducing risk preferably across multiple sectors.

a. Apuuli, B., J. Wright, C. Elias, I. Burton. (1998). "Reconciling National and Global Priorities in Adaptation to Climate Change: An Illustration from Uganda." Prepared for the IPCC Workshop on Adaptation to Climate Variability and Change, held in San Jose, Costa Rica, March 29-April 1, 1998.

2.2 WATER SECTOR TOOLS

The water sector tools described in this compendium, listed in Table 2-2, are mathematical models for assessing water resource adaptations to climate change, focusing on regional water supply and demand analysis of managed water systems. The models summarized here include long-range simulation tools such as WEAP and IRAS, short-range simulation models like RiverWare and WaterWare, and economic optimization models like Aquarius.

Table 2-2
Tools Covered in Water Sector

Table Titles (additional models included in table, where applicable)
WaterWare
Water Evaluation and Planning System (WEAP)
RiverWare
Interactive River and Aquifer Simulation (IRAS)
Aquarius

Water Ware

Description	This UNIX based software package is an advanced water resource simulation tool that incorporates numerous models and analyses for easy access to advanced tools of data analysis, simulation modeling, rule-based assessment, and multicriteria decision support for a broad range of water resources management problems. Designed to be a highly detailed operation analysis tool at shorter timesteps (hourly to daily). Strongly linked to water quality modeling of instream flows to determine optimal wastewater loading strategies. as well as related engineering, environmental, and economic aspects. WaterWare includes a number of simulation and optimization models and related tools, including a rainfall-runoff and water budget model, an irrigation water demand estimation model, dynamic and stochastic water quality models, a groundwater flow and transport model, a water resources allocation model, and an expert system for environmental impact and assessment.
Appropriate Use	Analysis and planning of complex, large-scale water resource management problems. Could be used to investigate realistic adaptation strategies under various hydrologic conditions. System includes both a rainfall/runoff model and a rule-based water resource system simulation tool, so a consistent hydrologic and water resource assessment could be made.
Scope	All locations; ground and surface water systems; national or site-specific.
Key Output	Water allocations at demand nodes, flows in river reaches, water quality constituents throughout water system, aquifer dynamics, and other water system components.
Key Input	Extensive data requirements. Hydrologic/water quality: Time series of basic hydrometeorological data (hourly to daily) covering at least one year or the period of interest for the long-term models). For groundwater module, aquifer characteristics. Hourly to daily water quality station observations. Economic: Discrete cost functions (investment and operational costs) for a set of alternative waste water treatment technologies.
Ease of Use	Fairly difficult to use given its broad scope.
Training Required	Significant training in computer modeling and the engineering, environmental, and economic aspects of water systems.
Training Offered	Software purchase includes on-site installation. Training courses and on-site training available (see below).
Computer Requirements	WaterWare is currently supported for UNIX servers (SUN Sparc/Solaris, IBM RS6000/AIX, HP Risc/HP-UX, Intel Pentium/Linux), with a minimum of 64 MB RAM and 128 MB of swap space. About 2 GB disk space is required; disk space requirements depend on the amount of geographical data (in particular satellite images) and monitoring data. A graphics resolution of 1280*1024 (256 simultaneous colors) is required for the X11 platforms.
Documentation	Documentation available from Environmental Software and Services, GmbH, Austria (see below).
Applications	River Thames in England; Lerma Chapala in Mexico; West Bank and Gaza in Palestine.
Contacts for Tools, Documentation, and Technical Assistance	Environmental Software and Services, GmbH, P.O. Box 100 A-2352 Gumpoldskirchen, Austria; Tel: 43225263305; Fax: 432252633059; website: http://www.ess.co.at/WATERWARE/.
Cost	ECU30,000 for initial installation, support, and one-year license.
References	WaterWare: A Water Resources Management Information System - Palestinian case study. Available from Environmental Software and Services, GmbH, PO Box 100 A-2352 Gumpoldskirken, Austria.

Water Evaluation and Planning System (WEAP)

Description	This is a PC/DOS based surface and groundwater resource simulation tool, based on water balance accounting principles, which can test alternative sets of conditions of both supply and demand. The user can project changes in water demand, supply, and pollution over a long-term planning horizon to develop adaptive management strategies. WEAP is designed as a comparative analysis tool. A base case is developed, and then alternative scenarios are created and compared to this base case. Incremental costs of water sector investments, changes in operating policies, and implications of changing supplies and demands can be economically evaluated.
Appropriate Use	What-if analysis of various policy scenarios and long-range planning studies. Adaptive agriculture practices such as changes in crop mix, crop water requirements, canal linings; changes in reservoir operations; water conservation strategies water use efficiency programs, water pricing policies; changes in instream flow requirements; implications of new infrastructure development. Strengths include detailed demand modeling.
Scope	All locations, surface and groundwater systems; national or site-specific.
Key Output	Mass balances, water diversions, sectoral water use; benefit/cost scenario comparisons; pollution generation and pollution loads.
Key Input	Configuration of system and component capacities and operating policies. Extensive data entry. Water demand: Spatially explicit demographic, economic, crop water requirements; current and future water demands and pollution generation. Economic data: Water use rates, capital costs, discount rate estimates. Water supply: Historical inflows at a monthly timestep; groundwater sources. Scenarios: Reservoir operating rule modifications, pollution changes and reduction goals.
Ease of Use	Relatively easy to use. Requires significant data for detailed analysis.
Training Required	Moderate training/experience in resource modeling required for effective use.
Training Offered	Contact SEI for details regarding available training (see below).
Computer Requirements	IBM-compatible PC, DOS 3.1, 550 KB free RAM, 4.5 MB available on hard disk, mouse, and VGA monitor.
Documentation	WEAP User Guide V 97.0; available online at http://www.tellus.com as pdf file.
Applications	Has been used for projects in the Aral Sea; Beijing, China; Rio San Juan, Mexico; Rajasthan, India; and Cairo, Egypt.
Contacts for Tools, Documentation, and Technical Assistance	Paul Raskin, SEI director, Stockholm Environment Institute (SEI), Boston; SEI-Tellus Institute, 11 Arlington St., Boston, MA 02116-3411 USA; Tel: +1.617.266.5400; e-mail: weap@tellus.com; website: http://www.tellus.com.
Cost	Relatively low cost to obtain model documentation and software.
References	Raskin, P., E. Hansen, Z. Zhu, and D. Stavisky. 1992. "Simulation of water supply and demand in the Aral Sea region." Water International, 17(2)55-67. Evan Hansen. 1994. "WEAP- A system for tackling water resource problems." In Water Management Europe 1993/94: An annual review of the European water and wastewater industry. Stockholm Environment Institute: Stockholm. U.S. Water News, Oct. 1992. "Aral Sea is classic example of ecological suicide." No. V4 pg. 12.

RiverWare

Description	A general UNIX based river and reservoir modeling application with both operational and planning applications. This system offers multiple solution methodologies that include simulation, simulation with rules, and optimization. RiverWare can accommodate a variety of applications, including daily scheduling, operational forecasting, and long-range planning. Modeling framework is nonspatial (not GIS based). Because of its object-oriented nature, the modeling framework allows for the generation of new modeling methods that could include economically driven demand modeling.
Appropriate Use	The tool is most appropriately used to model resource demands on complex water systems governed by water law and intricate operating rules. For broader, water resource-related activity, WEAP or IRAS tools are preferable (less expensive, easier to implement, less data required). Uncertainty modeling related to parameter variance provides estimates of uncertainty in model output.
Scope	All locations; surface water systems; national or site-specific.
Key Output	Mass balances, detailed flow descriptions throughout the water system, water diversions, hydropower generation, hydropower tradeoffs to other operating objectives. Water quality descriptions of dissolved solids and water temperature.
Key Input	Water demand: Description of diversion requirements (no explicit, economically driven demand modeling at this time). Water supply: Historical inflows at multiple timesteps, reservoir characteristics, stream reach routing characteristics. No groundwater components currently available. Scenarios: Operating rules of system given as prioritized operating policy described through a rule-based computer programming language. Water quality: Return water temperatures from thermal plants.
Ease of Use	The flexibility of the system makes it a more difficult model to use. Ideally designed for detailed analysis, requiring significant data.
Training Required	Requires extensive knowledge of the physical characteristics of water systems. Knowledge of water systems modeling helpful.
Training Offered	CADSWES regularly holds training workshops in Boulder, CO (see below).
Computer Requirements	Sun SPARCstation with Solaris 2.x operating system.
Documentation	Detailed documentation available through CADSWES; RiverWare description at http://www.cadswes.colorado.edu.
Applications	Currently, modeling applications have focused on operational strategies of current systems. In the U.S., the model has been used to develop operational strategies for the Tennessee Valley Authority's (TVA) river/reservoir system at short time scales (daily). Used for evaluating operating policies on the Colorado River at longer timesteps (monthly).
Contacts for Tools, Documentation, and Technical Assistance	Center for Advanced Decision Support in Water and Environmental Systems (CADSWES), University of Colorado, Campus Box 428, Boulder, CO 80309-0428 USA; website: http://cadsweb.colorado.edu/riverware.
Cost	Licensed software entails high cost.
References	Zgona, M. et al., 1998. RiverWare: A general river and reservoir modeling environment. In Proceedings of the first federal interagency hydrologic modeling conference, held in Las Vegas, NV, Vol. 2/2. Eschenback, E. et al. 1998. Automatic object oriented generation of goal programming models for multi-reservoir management. Available from CADSWES, Univ. of Colorado, Campus Box 428, Boulder, CO 80309.

Interactive River and Aquifer Simulation (IRAS)

Description	This tool is a PC based surface water resource simulation tool, based on water balance accounting principles that can test alternative sets of conditions of both supply and demand. The river system is represented by a network of nodes and links, with the nodes representing aquifers, gauges, consumption sites, lakes, reservoirs, wetlands, confluences, and diversions. Links are river reaches or water transfers to the nodes. The model can simulate up to 10 independent or interdependent water quality factors at a submonthly timestep. Through data interfacing, IRAS can link to various external modules such as rainfall-runoff and to economic and ecological impact prediction programs.
Appropriate Use	Used in long-range planning to evaluate the performance or impacts of alternative designs and operating policies of regional water resource systems, ranging from simple to complex systems. It has more significant water quality modeling ability than WEAP, but does not include a detailed demand modeling environment. Strengths include modeling capability of groundwater, natural aquatic systems and water quality. Includes wetland analysis.
Scope	All locations; surface water systems; regional, national, or site-specific.
Key Output	System performance in meeting demand requirements; flows, storage volumes, energy, and water quality throughout system.
Key Input	Configuration of system and component capacities and operating policies. Water demand: Demand requirements at various nodes. Water supply: Historical inflows at various time steps, evaporation and seepage losses from system, aquifer recharge rates, wetland characteristics. Water quality: Waste loads. Scenarios: Reservoir operating rule modifications, pollution changes and reduction goals.
Ease of Use	Relatively easy to use. Detailed analysis requires significant data.
Training Required	Moderate training/experience in resource modeling and demand analysis required for effective use.
Training Offered	Contact RPA for details regarding available training (see below).
Computer Requirements	IBM-compatible PC with Windows 95. Recommended Pentium processor with 24MB RAM, 100MB disk space, and color monitor.
Documentation	Detailed users guide is available from RPA and the website shown in the contact information below.
Applications	Has been applied to evaluate designs and policies of river-aquifer systems in North America, Europe, Africa, and Asia.
Contacts for Tools, Documentation, and Technical Assistance	Marshall Taylor, Resources Planning Associates, Inc., 231 Langmuir Bldg., 95 Brown Road, Ithaca, NY 14850 USA; Tel: +1.607.257.4305; Fax: +1.607.257.4306; website: www.cfe.cornell.edu/research/urbanwater/IRAS.htm
Cost	Relatively low cost to obtain model documentation and software.
References	CH2M Hill, 1993. New Jersey Statewide Water Supply Master Plan, Task 4 Report: Preliminary Development of Water Supply Initiatives. Parsippany, NJ: CH2M Hill, Inc. Loucks, D.P., P.N. French and M.R. Taylor. 1995. IRAS - Interactive River-Aquifer Simulation: Program Description and Operation. Resources Planning Associates, Incorporated, Ithaca NY: Resources Planning Associates, Inc.

Aquarius

Description	A computer model depicting the temporal and spatial allocation of water flows among competing traditional and nontraditional water uses in a river basin. The model focuses on optimization of a nonlinear system, where supplies and requested demands are prescribed on the system. Water resource systems are described in a node-link architecture, with river reaches, reservoirs, lakes, and demand objects describing the system. A drag and drop user interface helps define the system layout, which is then translated into a quadratic objective function with linear constraints.
Appropriate Use	Determining economically efficient water destination strategies. Can be used in a full deterministic optimization mode, for general planning purposes, or in a quasi-simulation mode, with restricted foresight capabilities. Does not include explicit demand or supply modeling, so supplies and demands need to be pre-specified.
Scope	All locations; surface and groundwater systems; cost-effectiveness; national or site-specific.
Key Output	Economically efficient allocations that meet prescribed demands.
Key Input	Physical data: Dimensions and operational characteristics of water system components, such as maximum reservoir capacity, percent of return flow from an offstream demand area, powerplant efficiency. Economic data: Demand functions of the various water uses competing for water.
Ease of Use	Fairly easy to use. Straightforward user interface with limited modeling scope makes model setup time relatively short.
Training Required	Minimal training required. Requires knowledge of some optimization theory.
Training Offered	Questions regarding software availability and training can be directed to Gustavo E. Diaz (see below).
Computer Requirements	PC Windows 95 or NT.
Documentation	Model documentation is available from the author (see contact information below).
Applications	Authors not aware of applications in developing countries.
Contacts for Tools, Documentation, and Technical Assistance	Gustavo E. Diaz, Department of Civil Engineering, Colorado State University, Fort Collins, CO 80523; Tel: +1.970.491.5048; Fax: +1.970.491.7721; e-mail: gdiaz@lamar.colostate.edu; website: http://www.engr.colostate.edu/depts/ce/netscape/software/aquarius.
Cost	Model documentation and software is free for government agencies and for teaching and research purposes.
References	Diaz, G.E.; T.C. Brown. 1997. AQUARIUS: A modeling system for river basin water allocation. General Technical Report RM-GTR-299, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, 160 p.

2.3 COASTAL DECISION TOOLS

The coastal tools described in this compendium, listed in Table 2-3, assist the user in evaluating different coastal management strategies. These tools include decision-support and qualitative methodologies such as the UNEP Handbook Methodology, SPIM, Historical and Geographic Analogs (description of this tool provided in the "General" sector section), and the IPCC Common Methodology, which are useful as initial analyses for applications where little quantitative data are available. These bottom-up methodologies and are particularly relevant in developing countries where quantitative data is limited but local expertise is abundant. The other types of coastal sector tools, including COSMO, CORONA, NATWEST, and RamCo, are more quantitative, modeling the physical and/or economic impacts of climate change under a range of management options. These tools, which attempt to integrate the complex range of factors associated with coastal zone management, include a range of processes that are still the subject of fundamental research. Therefore, they remain primarily research, rather than planning and evaluation, methods. They provide interesting evaluations and are continually being improved, but they should currently be used in conjunction with more accessible methodologies such as UNEP and IPCC.

Table 2-3
Tools Covered in Coastal Sector

Table Titles (additional models included in table, where applicable)
IPCC Common Methodology
UNEP Handbook Methodology
Decision Support Models (COSMO, CORONA, NATWEST)
The South Pacific Island Methodology (SPIM)
RamCo

IPCC Common Methodology

Description	This framework incorporates expert judgment and data analysis of socioeconomic and physical characteristics to assist the user in estimating a broad spectrum of impacts from sea-level rise, including the value of lost land and wetlands. It presents a list of analyses that should be done, but does not explicitly instruct the user on how to perform the analyses. Information from this methodology is generally used as a basis for further physical and economic modeling. The user follows seven steps: (1) delineate the case study area; (2) inventory study area characteristics; (3) identify the relevant socioeconomic development factors; (4) assess the physical changes; (5) formulate response strategies; (6) assess the Vulnerability Profile; (7) identify future needs.
Appropriate Use	This approach is most useful as an initial, baseline analysis for country level studies where little is known about coastal vulnerability.
Scope	Coastal; regional and global analysis.
Key Output	Vulnerability profile and the list of future policy needs to adapt both physically and economically. A range of impacts of sea-level rise, including land loss, value and uses of the lost land, wetland losses, etc.
Key Input	Physical and socioeconomic characteristics of the national coastal zone.
Ease of Use	Requires considerable knowledge on a range of techniques for estimating biophysical and socioeconomic impacts of sea-level rise and adaptation.
Training Required	Significant training required to complete the 7 steps (weeks or months); often performed by external consultants rather than in-country experts.
Training Offered	No formal training currently offered; contact CZMS for technical assistance.
Computer Requirements	Methodology does not explicitly state how to perform analyses; analytical method chosen by the user will determine the computer needs.
Documentation	IPCC CZMS, 1992. Global Climate Change and the Rising Challenge of the Sea. Report of the Coastal Zone Management Subgroup. IPCC Response Strategies Working Group, Rijkswaterstaat, The Hague.
Applications	Used in many coastal countries, including within the Dutch Country studies program, and in an adapted form in the U.S. Country Studies Program (e.g., Germany, Poland, Netherlands, Guyana, Vietnam, Bangladesh).
Contacts for Tools, Documentation, and Technical Assistance	Coastal Zone Management Centre, P.O. Box 20907, NL-2500 EX, The Hague, The Netherlands; Tel: (1-70)311.4364, Fax: (31-70)311-4380.
Cost	No cost to obtain documentation.
References	Nicholls, R.J. 1995. Synthesis of vulnerability analysis studies. In Proceedings of WORLD COAST 1993, Ministry of Transport, Public Works and Water Management, The Netherlands. pp. 181-216. Bijlsma, L., Ehler, C.N., Klein, R.J.T., Kulshrestha, S.M., McLean, R.F., Mimura, N., Nicholls, R.J., Nurse, L.A., Perez Nieto, H., Stakhiv, E.Z., Turner, R.K., and Warrick, R.A. 1996. Coastal Zones and Small Islands. In: R.T. Watson, M.C. Zinyowera, and R.H. Moss (eds), Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, (The Second Assessment Report of the Intergovernmental Panel on Climate Change, Working Group II), Cambridge University Press, Cambridge, pp. 289-324. Klein, R.J.T. and R.J. Nicholls. In press. Assessment of coastal vulnerability to climate change. Ambio.

UNEP Handbook Methodology

Description	The UNEP Methodology establishes a generic framework for thinking about and responding to the problems of sea-level rise and climate change. The user goes through the following seven guiding steps: (1) define the problem, (2) select the method, (3) test the method, (4) select scenarios, (5) assess the biogeophysical and socioeconomic impacts, (6) assess the autonomous adjustments, (7) evaluate adaptation strategies. The last step is itself split into 7 substeps. At each step, methods are suggested but the choice is left up to the user.
Appropriate Use	This approach is useful in a range of situations, including subnational, or national level studies. It could comprise the first study, or follow earlier studies such as those completed using the IPCC Common Methodology. Information gathered with this methodology can then be used as input for future modeling.
Scope	Coastal; regional, national, or global.
Key Output	Evaluation of a range of user-selected impacts of sea-level rise and potential adaptation strategies according to both socioeconomic and physical characteristics.
Key Input	Qualitative physical and socioeconomic characteristics of the national coastal zone.
Ease of Use	Fairly simple framework. As the level of analysis is not prescribed, the ease of use will depend on the level of analysis that is attempted.
Training Required	Depends on user expertise, but it is likely that some training is required to complete the seven steps.
Training Offered	No formal training currently offered, although technical assistance is available for countries within the UNEP program.
Computer Requirements	No explicit requirements, although using information in this framework for future modeling will require computers.
Documentation	Klein, R.J.T. and R.J. Nicholls. 1998. Coastal zones. Chapter 7 in: Feenstra, J., I. Burton, J. Smith, and R. Tol (eds.). 1998. Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies. United Nations Environment Programme, Nairobi, and Institute for Environmental Studies, Vrije Universiteit, Amsterdam. (Version 2.0).
Applications	Used in several countries, including the Cameroon, Antigua and Barbuda, Estonia, Pakistan, and Cuba.
Contacts for Tools, Documentation, and Technical Assistance	Jan Feenstra, Institute for Environmental Studies, Vrije Universiteit, Amsterdam; Tel: 31.20.444.9550; e-mail: jan.feenstra@ivm.vu.nl.
Cost	No cost to obtain documentation.
References	Klein, R.J.T. and R.J. Nicholls. In press. Assessment of coastal vulnerability to climate change. Ambio.

Cost	No cost to obtain documentation.
References	Klein, R.J.T. and R.J. Nicholls. In press. Assessment of coastal vulnerability to climate change. Ambio.

Decision Support Models: COSMO (COastal zone Simulation Model), CORONA (COastal zone ROle-play Numerical Application), and NATWEST

Description	COSMO, CORONA, and NATWEST are computer-based decision-support models that allow coastal zone managers to evaluate potential management strategies in different scenarios, including long-term climate change. COSMO and NATWEST are similar tools, developed for different site-specific applications. They demonstrate the main steps in the preparation, analysis and evaluation of Coastal Zone Management (CZM) plans. The programs are interactive tools that allow coastal zone managers to explore the impacts of development projects and environmental and coastal protection measures. They calculate various criteria, including long term effects of climate change, reflecting the use of the coastal zone. The user can explore a number of predefined cases as an educational tool, or specify new development scenarios and combinations of measures as a decision-making tool. A more complex version of COSMO and NATWEST, CORONA has been developed to demonstrate some more realistic characteristics, constraints and limitations of institutional arrangements for CZM. The program simulates day-to-day management of a coastal zone from the perspective of four organizations: (1) the city government, (2) the public works department, (3) the environment department and (4) the private sector. Each of these four roles takes annual decisions, within their means/budget and mandate, to further their own objectives.
Appropriate Use	Decision-support models are useful as educational tools about the relationship of adaptation to climate change within the broader context of coastal zone management. This methodology is used to help determine the advantages and disadvantages of adaptation alternatives, either as an educational or decision-support tool, in conjunction with other, more quantitative analyses.
Scope	All locations, coastal, national or site-specific.
Key Output	The outcome of a range of different management options.
Key Input	The user's chosen management strategy.
Ease of Use	Easy to use for educational purposes, although analysis of actual management plans requires more data.
Training Required	For educational purposes they require little training, although as a decision-support tool they require more knowledge of physical and socioeconomic characteristics of the situation.
Training Offered	Coastal Zone Management Centre, P.O. Box 20907, NL-2500 EX, The Hague, The Netherlands; Tel: (1-70)311.4364, Fax: (31-70)311-4380.
Computer Requirements	Standard PC (Pentium or better).
Documentation	Resource Analysis and Coastal Zone Management Centre, 1994. COastal zone Simulation Model (COSMO) Manual, Coastal Zone Management Centre, National Institute for Coastal and Marine Management, The Hague. Rijsberman, F.R., R.S. Westmacott & D. Waardenburg. 1995. CORONA: Coastal Resources Management Roleplay. Trainers' Manual. Resource Analysis, Delft, and Coastal Zone Management Centre, National Institute for Coastal and Marine Management, The Hague.
Applications	Used in training for CZM, including adaptation to climate change.
Contacts for Tools, Documentation, and Technical Assistance	Coastal Zone Management Centre, The Hague; Tel: 31.70.3114.364.
Cost	US$150 from Coastal Zone Management Centre.
References	See documentation above.

The South Pacific Island Methodology (SPIM)

Description	The South Pacific Island Methodology is an index-based approach that uses relative scores to evaluate different adaptation options in a variety of scenarios. The coastal zone is viewed as six interacting systems. There are three "hard" systems, the natural environment, the people, and infrastructure, and three "soft" systems, which encompass the less tangible elements of the coastal system, the institutions, the sociocultural factors, and the economic system. These are further divided into subsystems. The user gives each subsystem a vulnerability and a resilience score from -3 to +3, based on expert judgment, for the following scenarios: (1) today's situation, (2) the future with sea-level rise and no management, and (3) the future with sea-level rise and optimum management. For each subsystem, the two values are combined to produce a sustainable capacity index for each scenario.
Appropriate Use	SPIM is particularly useful in coastal settings where there is limited quantitative data but considerable experience and qualitative knowledge. Can be used during initial evaluation phases to analyze a range of possible adaptation options. Should be followed by a more quantitative analysis of the chosen option.
Scope	All locations, although most relevant to the South Pacific Islands; regional.
Key Output	Defines a sustainable capacity index for the subsystems defined.
Key Input	Expert judgment and qualitative information on the relative performance of various adaptation options.
Ease of Use	Relatively easy to use because it requires very little quantitative data.
Training Required	The SPIM is designed so that limited training is required, although background knowledge of physical, social, and economic characteristics of the area is helpful.
Training Offered	No formal training currently.
Computer Requirements	None.
Documentation	Yamada, K., P.D. Nunn, N. Mimura, S. Machida, and K. Yamamoto, 1995. Methodology for the assessment of vulnerability of South Pacific island countries to sea-level rise and climate change. Journal of Global Environment Engineering, 1, 101-125.
Applications	Used in several countries, including Fiji.
Contacts for Tools, Documentation, and Technical Assistance	Prof. N. Mimura, CWES, Ibaraki University 4-12-1 Nakanarusawa, Hitachi, Ibaraki 316, Japan; Tel: 81.294.38.5169. Prof. P. Nunn, University of the South Pacific, Suva, Fiji; Tel: 679.313.900; Fax: 679.301.305.
Cost	No cost for documentation, although cost of the analysis itself will depend on the availability and cost of data and local experts.
References	Kay, R.C. and J.E. Hay, 1993. A decision support approach to coastal vulnerability and resilience assessment: a tool for integrated coastal zone management. In: R.F. McLean and N. Mimura (eds.). Proceedings of the IPCC/WCC'93 Eastern Hemisphere Workshop, Tsukuba, 3-6 August 1993. Department of Environment, Sport and Territories, Canberra, pp. 213-225. Nunn, P.D., W. Aalbersberg, W.C. Clarke, W. Korovulavula, N. Mimura, E. Ohno, K. Yamada, M. Serizawa, and S. Nishioda, 1996. Coastal Vulnerability and Resilience in Fiji: Assessments of Climate Change Impacts and Adaptation, Phase IV. South Pacific Regional Environmental Programme (SPREP), Environment Agency, Government of Japan (EAJ) and Overseas Environmental Cooperation Center, Japan (OECC).

RamCo

Description	RamCo is an Excel-based prototype decision support tool designed as a means of asking structured questions about how external and internal components of coastal zone management problems interact. The socioeconomic system is explicitly defined and can interact with the physical effects of climate change, as well as changes in global trade patterns. It is the first prototype of an information system which is to evolve into a Generic Decision Support Environment.
Appropriate Use	Because RamCo is an evolving approach, it is still used mostly as an educational tool, although it has been used in analytical situations (see Applications). Scope of applicability is currently limited by availability of GIS data for specific regions.
Scope	All locations where GIS data is available; coastal; regional.
Key Output	The outcome of a range of different user-defined scenarios and management options.
Key Input	The user's chosen scenarios and management strategies.
Ease of Use	The Demo Guide is easy to follow without training.
Training Required	Requires little training for educational purposes, although the documentation is only for demonstration and does not explain how to set up another site for analysis.
Training Offered	Coastal Zone Management Centre, The Hague; Tel: 31.70.3114.364.
Computer Requirements	Pentium or better, Windows 95, Microsoft Excel (version 7.0), IDRISI for Windows. See page 15 of documentation.
Documentation	Uljee, I., Engelen, G. & White, R. 1996. RamCo Demo Guide Version 1.0, Coastal Zone Management Centre, National Institute for Coastal and Marine Management, PO Box 20907, 2500EX The Hague, The Netherlands.
Applications	St. Lucia, Sulawesi.
Contacts for Tools, Documentation, and Technical Assistance	Coastal Zone Management Centre, National Institute for Coastal and Marine Management, PO Box 20907, 2500EX The Hague, The Netherlands; Tel: 31.70.3114.364. Modeling and Simulation Research Group, Research Institute for Knowledge Systems BV, PO Box 463, Tongerstraat 6, 6200 AL Maastricht, The Netherlands.
Cost	US$150 from Coastal Zone Management Centre.
References	Engelen, G., R. White, and I. Uljee, 1993. Exploratory modelling of socio-economic impacts of climatic change. In G.A. Maul (Ed.), Climatic Change in the Intra-Americas Sea. London: Edward Arnold, pp. 350-368. Engelen, G., R. White, I. Uljee, and S. Wargnies, 1996. Numerical modeling of small island socio-economics to achieve sustainable development. In G.A. Maul, (Ed.), Small Islands: Marine Science and Sustainable Development, Coastal and Estuarine Studies Volume 51, Washington DC: American Geophysical Union, pp. 437-463.

2.4 AGRICULTURAL SECTOR TOOLS

The agricultural sector tools described in this compendium, listed in Table 2-4, range from sector-wide economic analyses to farm-level crop models. The crop process models address the impact of various management and climate change scenarios on both multiple crops (EPIC, GAPS) and single crops (ICASA, ALFALFA). Also included is a quantitative decision-support system (CROPWAT) designed to aid users in evaluating potential changes in irrigation and water management practices resulting from adaptation to climate change. The economic models, Ricardian Analysis and Input-Output Accounting, assist the user in evaluating the economic impacts of changing land values, supply and demand, and commodity producing resulting from climate change.

Table 2-4
Tools Covered in Agricultural Sector

Table Titles (additional models included in table, where applicable)
International Consortium for Application of Systems Approaches to Agriculture (ICASA) — International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Family of Models
General-Purpose Atmospheric Plant Soil Simulator (GAPS 3.1)
Erosion Productivity Impact Calculator (EPIC)
CROPWAT
Alfalfa 1.4
AFRC-Wheat
RICEMOD
GOSSYM/COMAX
GLYCIM
Econometric (Ricardian-based) Models
Input-Output Modeling (with IMPLAN)

Process Crop Models: International Consortium for Application of Systems Approaches to agriculture (ICASA) -- International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Family or Models

Description	The ICASA-IBSNAT suite of process crop models is structured as a decision support system for agrotechnology transfer (DSSAT) and evaluating agronomic adaptations. The suite includes all CERES and GRO models plus the SUBSTOR potato model for simulating up to 16 crops (e.g., maize, wheat, barley, sunflower, sugarcane, chickpea, tomato, and pasture). The ICASA/IBSNAT DSSAT is a computer software program combining crop, soil, and weather data bases, management programs, and crop models and application programs to simulate multiyear outcomes of crop management strategies. Its crop simulation models have identical modules for the simulation of the soil, water, and nitrogen balances, an important factor in crop rotation simulations. A graphics program displays soil moisture and nitrogen by depth over time. Programs have been developed for spatial application of the crop models and linkage with geographic information systems (GIS).
Appropriate Use	DSSAT allows users to ask "what if" questions and simulate results related to improved understanding of the influence of season, location, and management on the growth processes of plants. Particularly useful for evaluating agronomic adaptations such as changes in planting dates and maturity classes of cultivars.
Scope	All locations; agricultural sector; site-specific, although can be extrapolated to a national level using GIS.
Key Output	Changes in crop yields and yield components relative to different climate change scenarios.
Key Input	Data on a site's soils, climate, and management.
Ease of Use	For trained agronomists, DSSAT training should only take a day to acquire skills to conduct simple simulations.
Training Required	Requires advanced knowledge of plant growth processes. The DSSAT, with its embedded models, was designed for use by trained agronomists.
Training Offered	Fee-based training courses are offered regularly by IBSNAT (see below).
Computer Requirements	Any 486 or better PC compatible computer with 640K of RAM, minimum free RAM of 590K, and a hard disk. Complete installation requires 25 MB of disk space, DOS version 3.3 or later, a VGA graphic adapter or better, and a math coprocessor (recommended).
Documentation	Available at: http://agrss.sherman.Hawaii.edu/dssat.
Applications	Used by numerous countries in the U.S. Country Studies Program, including Egypt, Kazakhstan, and Uruguay.
Contacts for Tools, Documentation, and Technical Assistance	Dr. James W. Jones, Dr. Johan Bouma, IBSNAT, 2500 Dole Street, Krauss 22, Honolulu, HI 96822 USA; Tel: +1.808.956.8858; Fax: +1.808.956.3421; e-mail: gordont@hawaii.edu.
Cost	US$495 for DSSAT Version 3.5.
References	Uehara, G. 1985. The International Benchmark Site Network for Agrotechnology Transfer. In W. Day and R.K. Atkin (eds.)., Wheat Growth and Modeling, New York: Plenum Publishing, pp. 271-274.

Process Crop Models: General-Purpose Atmospheric Plant Soil Simulator (GAPS 3.1)

Description	GAPS is a dynamic DOS or Windows-based simulation software package of the soil-plant-atmosphere continuum, with crop management explicit in the model. It can simulate a sequence of crops and climates in a single simulation run. Used to examine the influence of climate on different aspects of crop management (e.g., the effects of climate variability on the number of field-days for getting equipment into fields).
Appropriate Use	Intended for use in research and teaching the principles and practice of dynamic simulation modeling of the soil-plant-atmosphere system.
Scope	All locations; agricultural sector; site-specific, although can be extrapolated using GIS to a national level.
Key Output	Crop yield and yield components.
Key Input	Data on the site's soils, climate, and management.
Ease of Use	High skill and time commitment required to prepare and run GAPS.
Training Required	Requires extensive training in crop management and computer modeling.
Training Offered	Self-instruction using manual.
Computer Requirements	Any PC that uses DOS or Windows 95 (or better). A batch version for large numbers of repetitive simulations is available.
Documentation	Buttler, I.W. and S. Riha. 1989. GAPS: A General Purpose Simulation Model of the Soil-Plant-Atmosphere System, Version 3.1. User's Manual. Ithaca, NY: Dept. of Agronomy, Cornell University. Can be downloaded from: http://www.scas.cit.cornell.edu/sjr4/gaps.html#Copy.
Applications	Used to examine farm-level impacts of climate change on agriculture in the midwestern U.S.
Contacts for Tools, Documentation, and Technical Assistance	Dr. Susan J. Riha, Dept. of Soil, Crop, and Atmospheric Sciences, Cornell University, 140 Emerson Hall, Ithaca, NY 14853 USA; Tel: +1.607.255.6143; e-mail: sjr4@cornell.edu.
Cost	No cost for model.
References	Kaiser, H., S. Riha, D. Wilks, D. Rossiter, and R. Sampath. 1993. A farm-level analysis of economic and agronomic impacts of gradual climate warming. American Journal of Agricultural Economics, 75:387-398.

Process Crop Models: Erosion Productivity Impact Calculator (EPIC)

Description	EPIC is an IBM, Macintosh, or Sun based generalized crop model that simulates daily crop growth on a hectare scale. Like most process plant growth models, it predicts plant biomass by simulating carbon fixation by photosynthesis, maintenance respiration, and growth respiration. Several different crops may be grown in rotation within one model execution. It uses the concept of light-use efficiency as a function of photosynthetically available radiation (PAR) to predict biomass. EPIC has been modified to simulate the direct effects of atmospheric carbon dioxide on plant growth and water use. Crop management is explicitly incorporated into the model.
Appropriate Use	This approach is useful for evaluating a limited number of agronomic adaptations to climate change, such as changes in planting dates, modifications to rotations (i.e., switching cultivars and crop species), changing irrigation practices and changing tillage operations. The parameter files are extremely sensitive to local conditions and EPIC can give grossly misleading results when relying on default settings as it is being tailored to different locations and cropping systems.
Scope	All locations; agricultural; site-specific.
Key Output	Response of crop yields, yield components, and irrigation requirements to climate change adaptations.
Key Input	Quantitative data on climate, soils, and crop management.
Ease of Use	Data intensive and difficult to use without sufficient qualifications. A person trained in general crop systems science with moderate programming skills should be able to use EPIC reliably with 3-4 days of intensive training.
Training Required	Requires technical modeling skills and a basic knowledge of agronomic principles.
Training Offered	Informal training offered; see below.
Computer Requirements	IBM-compatible PC, Macintosh, or UNIX-based Sun Workstation.
Documentation	Williams, J.R., C.A. Jones, P.T. Dyke. 1990. The EPIC model documentation. USDA-ARS Technical Bulletin No. 1768, Washington, DC: U.S. Department of Agriculture, pp. 3-92.
Applications	RAC analysis, drought assessment, soil loss tolerance tool, Australian sugarcane model (AUSCANE), pine tree growth simulator, global climate change analysis, farm level planning, drought impacts on residue cover, and nutrient and pesticide movement estimates for alternative farming systems for water quality analysis.
Contacts for Tools, Documentation, and Technical Assistance	Dr. Susan J. Riha, Dept. of Soil, Crop, and Atmospheric Sciences, Cornell University, 140 Emerson Hall, Ithaca, NY 14853 USA; Tel: +1.607.255.6143; e-mail: sjr4@cornell.edu.
Cost	No cost for model.
References	Williams, J.R., Jones, C.A., and Dyke, P.T. 1984. A modeling approach to determining the relationship between erosion and soil productivity. Transamerican Society of Agricultural Engineering 27:129-144. Easterling, W.E., N.J. Rosenberg, M.S. McKenney, C.A. Jones, P.T. Dyke, J.R. Williams. 1992. “Preparing the erosion productivity impact calculator (EPIC) model to simulate crop response to climate change and the direct effects of CO2.” in Special Issue: Methodology for Assessing Regional Agricultural Consequences of Climate Change, Agricultural and Forest Meteorology 59(1-2):17-34.

Irrigation Model: CROPWAT

Description	CROPWAT is a DOS or Windows based decision support system designed as a tool to help agro-meteorologists, agronomists, and irrigation engineers carry out standard calculations for evapotranspiration and crop water use studies, particularly the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation.
Appropriate Use	The model should be flexible enough to serve as a tool for testing the efficiency of different irrigation strategies (e.g., irrigation scheduling, improved irrigation efficiency) under climate change. Does not have the capacity of simulating the direct effects of rising atmospheric carbon dioxide concentrations on crop water use.
Scope	All locations; agricultural sector; site-specific.
Key Output	Reference evapotranspiration, crop water requirements, and crop irrigation requirements.
Key Input	Climatic and crop data (CLIMWAT database, included with the program) for calculations of crop water requirements and irrigation requirements. The development of irrigation schedules and valuation of rainfed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions.
Ease of Use	Relatively easy to use for qualified experts with appropriate background.
Training Required	Intended for use by agricultural professionals because it requires background and training in agricultural modeling. Using the manual, an expert can learn how to use this tool within 1-2 days.
Training Offered	No formal training currently offered beyond the training manual.
Computer Requirements	PC supporting DOS or Windows. CROPWAT version 5.7, issued in 1992, is written in BASIC and runs in the DOS environment. CROPWAT for Windows contains a CROPWAT version in Visual Basic to operate in the Windows environment.
Documentation	CROPWAT for Windows and its manual are available in Acrobat format and can be downloaded from FAO's FTP server (ftp.fao.org) as CRW2W2.ZIP and CRW4W-MN.ZIP, respectively.
Applications	The CROPWAT database contains data for 6 continental regions and 144 countries. It has been used to develop irrigation schedules under various management conditions to evaluate rainfed production and drought effects and efficiency of irrigation practices.
Contacts for Tools, Documentation, and Technical Assistance	Martin Smith, Senior Irrigation Management Officer, Water Resources, Development, and Management Service, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy; Tel: (39-06) 57053818; Fax: (39-06) 57056275; e-mail: Martin.Smith@FAO.ORG.
Cost	No cost to obtain model documentation or software.
References	FAO. 1992. CROPWAT — A Computer Program for Irrigation Planning and Management. FAO Irrigation and Drainage Paper No. 46. Rome: Food and Agriculture Organization.

Process Crop Models: Alfalfa 1.4

Description	Alfalfa 1.4 is a DOS, Windows, or Macintosh based model that simulates growth and development of the alfalfa plant, based in integrative plant physiology and morphology. The model permits simulation of the diurnal patterns of production processes and growth for studying the influences of temperature, radiation, water deficit, and carbon supply. Beginning with tissue and organ level information, the growth of shoots is simulated for up to five age classes of stems. Perennial, underground structures (crown, taproot, and fibrous roots) are simulated over 10 soil layers. The model includes variations in plant population so that overwintering and stand persistence can be simulated.
Appropriate Use	Alfalfa offers a robust structure suited to a wide range of management issues and for coupling to insect and disease models. Several usual adaptation strategies for coping with climate change (changes to cultivars, planting dates) may be tested.
Scope	All locations; agricultural sector; site-specific.
Key Output	Total above-ground biomass (edible yield).
Key Input	The program is driven by daily weather data from standard meteorological reports. Hourly weather variables are derived from the daily data to support the model's hourly time advance.
Ease of Use	Relatively easy to use with sufficient background.
Training Required	Advanced programming skills (knowledge of FORTRAN language) are helpful, agronomic background required.
Training Offered	No formal training currently offered beyond the training manual.
Computer Requirements	Can be run in DOS, Windows, or Macintosh environments. Instructions for downloading given at the website below.
Documentation	Denison, R.F. and B. Loomis. 1989. An Integrative Physiological Model of Alfalfa Growth and Development. UC ANR Publication 1926, Davis: University of California.
Applications	Has been used by farmers in the U.S.
Contacts for Tools, Documentation, and Technical Assistance	R. Ford Denison, Agronomy and Range Science, University of California, Davis, Davis, CA 95616 USA; Tel: +1.530.752.9688; e-mail: rfdenison@ucdavis.edu.
Cost	Program and manual available for US$25.
References	Denison, Ford and Bob Loomis. 1989. An Integrative Physiological Model of Alfalfa Growth and Development. UC ANR Publication 1926.

Process Crop Models: AFRC-Wheat

Description	AFRC-Wheat is a FORTRAN-based mechanistic model that incorporates crop response to water and nitrogen constraints. Model processes include phenological development, partitioning of photosynthesis, growth of leaf and stems, senescence, biomass accumulation, and root system dynamics. The model uses a threshold of accumulated growing degree days above a base and below a ceiling temperature to regulate growth.
Appropriate Use	Used to investigate the interannual variation in the length of vegetative and floral development and grain filling periods driven by historic climate data. Results of experiments with the AFRC-wheat model run with climate change can be extrapolated to national scale crop potential estimations using GIS technology.
Scope	All locations; agricultural sector; national- or site-specific.
Key Output	Yield and yield components.
Key Input	Weather data such as daily values of max, min, dry and wet bulb, temperature, solar radiation, sunshine hours, rainfall, wind, etc.
Ease of Use	For experts with sufficient background, the model is easy to use.
Training Required	Requires basic knowledge of climate, crop agronomy, crop physiology, and soils.
Training Offered	See web site below for details.
Computer Requirements	VAX computers (in FORTRAN 77) or IBM PC-compatibles (DOS v3.3 or higher).
Documentation	http://mwnta.nmw.ac.uk/GCTEFocus3/series.htm
Applications	AFRC-Wheat has been used in the United Kingdom by AFRC and University of Oxford, Italy by the University of Florence, in France by INRA Avignon, in Hungary by the University of Budapest, in Germany by the University of Bonn, in New Zealand by Crop and Food Research Limited, and in Syria by ICRISAT.
Contacts for Tools, Documentation, and Technical Assistance	Dr. John R. Porter, Dept. of Agricultural Services, Royal Agricultural and Veterinary University, agrovej 10, 2630 Taastrup, Denmark; Tel: 45.28.77/35.60; Fax: 45.35.28.21.75; e-mail: john.r.porter@agsci.kvl.dk.
Cost	Free for anyone in Global Change and Terrestrial Ecosystems (GCTE) Wheat Network.
References	Weir, A.H., P.L. Bragg, J.R. Porter, and J.H. Rayner. 1984. A winter wheat model without water or nutrient limitations. Journal of Agricultural Science, Cambridge, 102:371-383. Addiscott, T.M., P.J. Heys, A.P. Whitmore. 1986. Application of simple leaching models in heterogenous soils. Geoderma, 38:185-194. Addiscott, T.M. and A.P. Whitmore. 1987. Computer simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter, and spring. Journal of Agriculture Science, Cambridge, 109:141-157.

Process Crop Models: RICEMOD

Description	RICEMOD is a FORTRAN and BASIC based ecophysiological model for irrigated rice production. It includes a number of physical parameters, including accommodation of subroutines dealing with soil and plant chemistry as well as physical processes of the atmospheric environment. The model is very sensitive to soil parameters and has been expanded to consider soil water deficit. Model components include maximum leaf area index, timings of plant growth initiation and harvest, radiation-use efficiency (RUE), and harvest index (HI).
Appropriate Use	The model can be used to study the relative constraining effects of radiation, leaf blade nitrogen content, respiration rate, and assimilate partitioning on rice plant growth. Useful for predicting future production scenarios. The model does not include the influence of CO2.
Scope	All locations; agricultural sector; site-specific.
Key Output	Total area index (LA1, leaves and stem), growth rates, dry weights, dry matter partitioning, grain yield, number of grains, CO2 assimilation, amount of radiation absorbed by the canopy.
Key Input	Data intensive; requires soil, plant, and atmospheric data (rainfall, pan evaporation, radiation, minimum and maximum temperature, day length).
Ease of Use	Relatively easy to use, although requires some expertise and is fairly data intensive.
Training Required	Requires knowledge of soil physical properties and some background in agronomics.
Training Offered	IRRI (see below) offers training.
Computer Requirements	Programmed in FORTRAN IV and BASIC. Requires an IBM-compatible PC 370/135.
Documentation	McMennary, J. and J.C. O'Toole. 1985. RICEMOD: A Physiologically-Based Rice Growth Model. IRRI research paper series #87.
Applications	Used to indicate leaf water stress and predict the growth and yield component of different rice varieties in a number of rice-producing countries including the Philippines.
Contacts for Tools, Documentation, and Technical Assistance	Dr. John Sheehy, Chairman of the GCTE Rice Working Group, IRRI, PO Box 933, 1099 Manila, The Philippines; Tel: 63.2.8181926/884869; Fax: 63.2.8178470/8182087; e-mail: irri@cgiar.com; website: www.cgiar.org/irri.
Cost	Contact IRRI for information.
References	See documentation.

Process Crop Models: GOSSYM/COMAX

Description	GOSSYM/COMAX is a mechanistic cotton growth model and expert system that simulates cotton growth given selected weather, soil, and management practices. Management options include fertilizer and irrigation strategies. GOSSYM operates on daily time steps and calculates material balances for water and nitrogen using weather and soil data to predict crop growth and crop yield. The model also calculates material balances and soil nitrogen uptake. Useful in computing irrigation, planting time, and fertilization strategies for farmers.
Appropriate Use	Proven to be an effective aid to cotton growers, crop consultants, and researchers in the management of irrigation water, nitrogen, plant growth regulators, and crop termination chemicals. Useful in computing irrigation, planting time, and fertilization strategies for farmers and can be used in conjunction with GCMs or WGEN to examine the effects of changes in climate on crop production. Does not work well with intersecting insect data.
Scope	All locations; agricultural sector; site-specific.
Key Output	Crop yield and yield components.
Key Input	Soil moisture and bulk density for each soil horizon and weather data (including temperature, wind speed, solar radiation, and humidity).
Ease of Use	Relatively easy to use despite significant data requirements.
Training Required	Requires some knowledge of soil and plant physiology, although a user with sufficient background can gain proficiency with a few days of training.
Training Offered	Short training course offered (see below).
Computer Requirements	An IBM-compatible 486 with 4K of RAM and 80MB.
Documentation	Application manual available (see below).
Applications	Has been used in Spain, Greece, China, The Philippines, Australia (modified), Cameroon, and Thailand as well as many states in the U.S.
Contacts for Tools, Documentation, and Technical Assistance	Dr. James McKinion, USDA-ARS, Crop Simulation Unit, PO Box 536, Mississippi State, MS 39762, USA; Tel: +1.601.324.4375; Fax: +1.601.324.4371; e-mail: mckinion@csrumsu.ars.ag.gov.
Cost	Can be obtained free of charge by e-mailing sturner@ra.msstate.edu.
References	McKinion, J.M., D.N. Baker, F.D. Whisler, and J.R. Lambert. 1989. Application of GOSSYM/COMAX system to cotton crop management. Agricultural Systems 31:55-65. Watkins, K.B., Y.C. Lu, V.R. Reddy. 1998. An economic evaluation of alternative pix application strategies for cotton production using GOSSYM/COMAX. Computers and Electronics in Agriculture (20)3: 251.

Process Crop Models: GLYCIM

Description	GLYCIM is a dynamic soybean simulation model with hourly time steps. It predicts growth and yield of a soybean crop in response to climate, soil, and management practices by deterministic simulation of organ-level processes such as photosynthesis, transpiration, carbon partitioning, and organ growth and development.
Appropriate Use	Farmers use GLYCIM for pre-plant planning decisions like the selection of cultivar/soil type combination, planting date, and row spacing, and post-plant decisions like irrigation scheduling, harvest timing, and yield prediction. The use of the model for crop management, decision making, and input optimization shows promise in increasing profits to growers and improvements to environment and ground-water quality. Amendable to the testing of management adjustments to climate variation.
Scope	All locations; agricultural sector; site-specific.
Key Output	Output data includes plant height, water stress, nitrogen stress, stages of maturity, water content data, yield, and yield components.
Key Input	Requires daily maximum and minimum temperature, precipitation, and solar radiation data as input. Soil data are also required to execute the model (e.g., soil horizons, organic matter, and nitrogen content).
Ease of Use	GLYCIM demands more data inputs than many crop models, but once data input requirements are met at the user level, it is simple to use.
Training Required	Requires some knowledge about agronomy and soil science.
Training Offered	Mississippi State University and University of Idaho can provide training.
Computer Requirements	Requires an IBM-compatible 486, with 4F of RAM and 80MB.
Documentation	http://dino.wiz.uni-kassel.de/model_db/mdb/glycim.html.
Applications	Currently being used by farmers and several extension services in nine states in the U.S.
Contacts for Tools, Documentation, and Technical Assistance	Dr. James McKinion, USDA-ARS, Crop Simulation Unit, PO Box 536, Mississippi State, MS 39762 USA; Tel: +1.601.324.4375; Fax: +1.601.324.4371; e-mail: mckinion@csrumsu.ars.ag.gov.
Cost	Can be download ed free from website (see documentation).
References	http://wizard.arsusda.gov/rsml/accomp2.html.

Economic Models: Econometric (Ricardian-based) Models

Description	Econometric models are manipulated with climate change scenarios to predict the economic costs of adaptation. They estimate structural relations between historical climate and agricultural land values under the presumption that such relations reflect a steady-state level of adaptation of regional farming systems to local climate characteristics. These relations are cross-sectional (i.e., units of observation are geographic areas) and the geographic variation in land values is assumed to be partly regulated by differences in the quality of climate inputs. Parameter estimates embed the relative efficiency of current adaptation to a range of climate conditions (cold and warm).
Appropriate Use	Econometric models can capture the full range of economic adaptations that farmers and supporting institutions are likely to use in response to climate change. They are particularly suited to analysis that assumes no change in real crop prices in response to climate change. These tools do not estimate the cost of adaptation.
Scope	All locations; agricultural sector; national or regional.
Key Output	Potential changes in regional or national cropping patterns, land prices, production, revenues, and profits.
Key Input	Historical climate and land values.
Ease of Use	Because no established, or “canned” models exist, each application requires development of a unique, region-specific model.
Training Required	Expertise in principles of econometric modeling.
Training Offered	No formal training offered.
Computer Requirements	IBM-compatible PC.
Documentation	Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. The impact of global warming on agriculture: A Ricardian analysis. American Economic Review, 84(4): 753-751.
Applications	Econometric models have been used to estimate the economic cost/benefit of climate change for agriculture and forestry in the United States, Brazil, and India.
Contacts for Tools, Documentation, and Technical Assistance	Dr. Robert Mendelsohn, Yale University, 360 Prospect St., New Haven, CT 06511 USA; Tel: +1.203.432.5128; Fax: +1.203.387.0766; e-mail: robert.mendelsohn@yale.edu.
Cost	Varies, depending on data needs and resources required for developing a unique model.
References	Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. The impact of global warming on agriculture: A Ricardian analysis. American Economic Review, 84(4): 753-751. Mendelsohn, R. and J. Neumann (eds.). 1999. The Impacts of Climate Change on the U.S. Economy. Cambridge, England: Cambridge University Press. Dinar, A., R. Mendelsohn, R. Evenson, J. Parikh, A. Sanghi, K. Kumar, J. McKinsey, S. Lonergon. 1998. Measuring the Impact of Climatic Change on Indian Agriculture. World Bank Technical Report No. 409, Washington DC: The World Bank.

Economic Models: Input-Output Modeling (with IMPLAN)

Description	Input-output accounting (using the IMPLAN model as an example) describes commodity flows from producers to intermediate and final consumers. The total industry purchases of commodities, services, employment compensation, value added, and imports are equal to the value of the commodities produced. Industries producing goods and services for final use and purchases for final use (final demand) drive the model. Industries producing goods and services for final demand purchase goods and services from other producers. These other producers, in turn, purchase goods and services. This buying of goods and services continues until leakages from the region stop the cycle. The resulting sets of multipliers describe the change of output for every regional industry caused by a one dollar change in final demand for any given industry.
Appropriate Use	IMPLAN was designed to serve 3 functions: 1) data retrieval, 2) data reduction and model development, 3) impact analysis. Comprehensive and detailed data coverage of the entire U.S. by county, and the ability to incorporate user-supplied data at each stage of the model building process, provides a high degree of flexibility both in terms of geographic coverage and model formulation. Can be used to look at the effects of adaptations such as changes in economic policies (e.g., removal or imposition of subsidies) toward agriculture. IMPLAN was designed specifically for the U.S., but the basic model structure can be adapted and applied to other countries where data is available.
Scope	United States (although can be adapted for use in other countries); agricultural sector; national- or regional-specific.
Key Output	Being demand-driven, most input-output models are structured to trace changes in the flows of capital and labor between industries in response to a change in final demand. Climate change impact analysis often uses input-output models to trace the interindustry flows in response to climate-induced changes in supply.
Key Input	The IMPLAN database consists of 1) a U.S. level technology matrix and 2) estimates of sectoral activity for final demand, final payments, industry output and employment for each county in the U.S., along with state and national totals.
Ease of Use	Commercially available input-output models like IMPLAN are relatively easy to use, although modification from demand to supply driven models is facilitated with an economics background.
Training Required	Training in the use of these models, along with a background in economic analysis, is essential.
Training Offered	MIG Workshops (see below) provides training for the use of IMPLAN in economic analysis. Workshops are held either in MIG's Minnesota office or at user's site.
Computer Requirements	Requires a PC, Windows, and the IMPLAN software package. Adobe Acrobat needed to download user manual from the website.
Documentation	A user manual for IMPLAN, available from the MIG, Inc. website listed below, may be downloaded to a PC using Adobe software.
Applications	Applied by numerous state, federal, academic, and private institutions in the U.S. such as U.S. Department of Agriculture Forestry Service, the Illinois Department of Natural Resources, and Cornell University.
Contacts for Tools, Documentation, and Technical Assistance	*Tools and Documentation:* MIG, Inc., 1725 Tower Drive West, Suite 140, Stillwater, MN 55082 USA; Tel: +1.651.439.4421; Fax: +1.651.439.4813; e-mail: info@implan.com; website: www.implan.com. *Technical* Assistance: www.IMPLANPro.com
Cost	IMPLAN costs vary depending on scope of study (county, state, or national). County-level software costs $150 per county. State-level software averages about $1,500 per state.
References	Bowes, M. and P. Crosson. 1993. Consequences of climate change for the MINK economy: Impacts and responses. Climate Change, 24:131-158.

2.5 HUMAN HEALTH SECTOR TOOLS

The health tools described in this compendium, listed in Table 2-5, model the health impacts of climate change on disease occurrence and mortality. They aid in identifying areas of high risk, and are particularly useful for areas currently endemic to diseases like malaria or dengue fever, or in close proximity to such areas. Modeling adaptation strategies in the health sector is an emerging field, so the number of tools available is still limited. A description of Historical and Geographic Analogs is also provided, but is included in the section describing general tools.

Table 2-5
Tools Covered in Human Health Sector

Table Titles (additional models included in table, where applicable)
MIASMA (Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)
DENSiM (Dengue Simulation Model)

MIASMA (Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)

Description	MIASMA is a Windows-based modeling application that models several health impacts of global atmospheric change and include simulation for several modules: 1) vector-borne diseases, including malaria, dengue fever, and schistosomiasis; 2) thermal heat mortality; and 3) UV-related skin cancer due to stratospheric ozone depletion. The models are driven by both population and climate/atmospheric scenarios, applied across baseline data on disease incidence and prevalence, climate conditions, and the state of the stratospheric ozone layer.
Appropriate Use	MIASMA can be used to link GCM output of climate change or scenarios of stratospheric ozone depletion to any of the human health outcomes mentioned above. Applicability of this model is limited only by the scope of available data.
Scope	Health, regional and global analysis.
Key Output	For the thermal stress module: cardiovascular, respiratory, and total mortality. For skin cancer module: malignant melanoma and nonmelanoma skin cancer. For vector-borne disease modules: cases and fatalities from malaria, and incident cases for dengue fever and schistosomiasis.
Key Input	Climate input is module or disease specific. For thermal stress, maximum and minimum temperature are required. For skin cancer, the column loss of the stratospheric ozone over the site is required to determine the level of UV-B radiation potentially reaching the ground. Require maximum and minimum temperature and rainfall. Vector-borne diseases also require other baseline data, determinable by local experts. For example, for malaria it would help to know the level of partial immunity in the human population and the extent of drug resistant malaria in the region.
Ease of Use	After a short training, the computer simulations should not be difficult.
Training Required	Requires familiarity with computer modeling; some mathematical skills may be beneficial.
Training Offered	Dr. Pim Martens (see below).
Computer Requirements	Pentium PC, 16 MB RAM, Windows 95 or NT4 or higher. For hard drive installation: 20MB free disk space. A monitor resolution of 1074 x 768 is recommended. To view the documentation and help files, either Netscape Navigator (version 4 or higher) or Microsoft Internet Explorer (version 4 or higher) is recommended.
Documentation	Martens P. Health and Climate Change: Modeling the Impacts of Global Warming and Ozone Depletion. Earthscan Publications, 1998.
Applications	Thermal stress module has been applied to 20 international cities. Skin cancer module has been applied to The Netherlands and Australia. Vector-borne disease module has been used globally, malaria module in Zimbabwe, and dengue module for Bangkok, San Juan, Mexico City, Athens, and Philadelphia.
Contacts for Tools, Documentation, and Technical Assistance	Dr. Pim Martens, ICIS, P.O. Box 616, 6200 MD Maastricht, The Netherlands; Tel: 31-43-388-3555; Fax: 31-43-321-1889; e-mail: p.martens@icis.unimaas.nl.
Cost	Low cost (price of shipping CD-ROM and documentation).
References	Martens, W. 1997. Health impacts of climate change and ozone depletion: an eco-epidemiological modelling approach. Dept. Mathematics. Maastricht, University of Maastricht: 158. Martens, W. J. M. 1998. Climate change, thermal stress and mortality changes. Soc Sci Med 46(3): 331-344. Martens, W. J. M., T. H. Jetten, et al. 1997. Sensitivity of malaria, schistosomiasis, and dengue to global warming. Climatic Change 35: 145-156. Martens, W. J. M., T. H. Jetten, et al. 1995. Climate change and vector-borne diseases: a global modelling perspective. Global Environmental Change 5(3): 195-209.

DENSiM (Dengue Simulation Model)

Description	DENSiM is an Excel-based model of mosquito-borne dengue fever transmission using site-specific climate and environmental parameters to estimate the risk of disease transmission. The model can also help determine the risk of dengue hemorrhagic fever (DHF) by calculating the shift in age distribution of human cases — a subsequent second infection by a different one of four dengue virus serotypes, may be a risk for DHF particularly in children. For preventing disease, this model can help estimate a target level mosquito population as a goal for vector control. This model can also help in determining high risk areas to focus control measures given changes in climate or climate variability. Given the broad range of input parameters, DENSiM can be used in a variety of situations.
Appropriate Use	This model can be used in any location currently endemic for dengue, or in close proximity to such areas. Considering the number of input parameters, this model can be adjusted for locations which vary in development of public health infrastructure or socioeconomic status. If the likelihood of dengue virus ever entering the area is low, this model would be of limited value.
Scope	Health, national or site-specific.
Key Output	Age-specific and type-specific seroprevalence of dengue infection.
Key Input	Climatic parameters essential to the model include daily maximum and minimum temperature; saturation deficit (or inverse of relative humidity); and rainfall. A site-specific survey of small containers (breeding sites or mosquito larval habitat) must be conducted (preferably by a trained entomologist). Larval sampling and hatching to determine proportion of Aedes aegypti is beneficial for more accurate simulations. Information on the local human population, such as age structure and demographics, must be known, as well as the level of dengue immunity in the population. Ideally, the seroprevalence of specific anti-dengue antibodies should be known for better simulation results. If data are unavailable, estimated immunity can provide a range of modeled outputs.
Ease of Use	Once training is acquired, the simulation modeling is not difficult, and consultation with the model developer, Dr. Dana Focks, is encouraged. Data requirements are extensive, although estimations can be used if quantitative data are unavailable.
Training Required	For the field parameterization, a trained entomologist is required. To conduct the computer model simulations, general computer skills and knowledge of Excel and similar programs may help.
Training Offered	Contact Dana Focks at USDA (see below).
Computer Requirements	PC, IBM compatible.
Documentation	Focks, D. A., E. Daniels, et al. 1995. A simulation model of the epidemiology of urban dengue fever: literature analysis, model development, preliminary validation, and samples of simulation results. American Journal of Tropical Medical Hygiene 53: 489-506.
Applications	Used by public health officials and health ministries in Trinidad, Honduras, Thailand, Indonesia, Texas, Puerto Rico.
Contacts for Tools, Documentation, and Technical Assistance	Dr. Dana Focks, Medical, Agricultural and Veterinary Entomological Research Laboratory, U.S. Department of Agriculture, 1600-1700 SW 23rd Dr., Gainesville, FL 32608 USA; Tel: +1.352.374.5976; Fax: +1.352.374.5818; e-mail: focks@gainesville.usda.ufl.edu.
Cost	No cost to obtain the model or the documentation.

DENSiM (Dengue Simulation Model) (cont.)

References	Focks, D. A., E. Daniels, et al. 1995. A simulation model of the epidemiology of urban dengue fever: literature analysis, model development, preliminary validation, and samples of simulation results. Am J Trop Med Hyg 53: 489-506. Focks, D. A., D. G. Haile, et al. 1993. Dynamic life table model for Aedes aegypti (L.) (Diptera: Culicidae). Simulation results and validation. J Med Entomol 30: 1018-1028. Focks, D. A., D. G. Haile, et al. 1993. Dynamic life table model for Aedes aegypti (L.)(Diptera: Culicidae). Analysis of the literature and model development. J Med Entomol 30: 1003-17. Jetten, T. H. and D. A. Focks. 1997. Changes in the distribution of dengue transmission under climate warming scenarios. Am J Trop Med Hyg. Patz, J. A., W. J. M. Martens, et al. 1998. Dengue fever epidemic potential as projected by general circulation models of global climate change. Environ Health Perspect 106(3): 147-153.

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