Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change

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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." The UNFCCC Secretariat took a first step in this direction when it produced a report in 1999 entitled *Compendium of Decision Tools to Evaluate Strategies for Adaptation to Climate Change*. The aim of that report was to understand the use and availability of such decision tools.

Since then, the adaptation assessment process has changed considerably and in some ways grown more sophisticated. The UNFCCC Secretariat has subsequently sought to update the original compendium and broaden its scope. The challenge of this effort is not only to expand the structure of the compendium to include new tools that have come into use and to modify it to include tools applicable to the entire process of vulnerability and adaptation assessment (not simply decision making), but also to reorganize it so as to capture the range of thinking reflected in the different recent approaches to the assessment process.

The earlier work (sometimes referred to as the first generation) in climate change impacts and adaptation studies focused more on impacts than on adaptation. The motivation for the research was often driven by the need to understand how great the impacts of climate change might be to know how much urgency to give to the mitigation agenda or the stabilization of greenhouse gas concentrations in the atmosphere. This work was facilitated by a number of "guidance documents," among which the most prominent were:

- SCOPE Report on impact Assessments (Kates et al., 1985)
- Intergovernmental Panel on Climate Change (IPCC) Guidelines (Carter et al., 1994; see Chapter 2 of this document)
- U.S. Country Studies Program (Benioff et al., 1996; see Chapter 2 of this document)
- United Nations Environment Programme (UNEP) Handbook (Feenstra et. al., 1988).

The first generation studies were generally based on climate scenarios derived from general circulation models (GCMs). The chosen scenarios were commonly applied to models of ecosystems, to specific species within an ecosystem, or to a component of the biogeophysical environment such as sea level; coastal zones, including coral reefs; the hydrological cycle; mountains; deserts; or small islands. These "first order" impacts were sometimes carried forward to the modeling of "second order" impacts on economic sectors such as agriculture, forestry, water resource management, human health, and so forth. Only at the end of a long research process was adaptation considered, and only infrequently were socioeconomic scenarios developed alongside the climate scenarios.

More recently there has been an upsurge in interest and concern about adaptation linked to current climate variability and current vulnerability in addition to the concern with future climate and vulnerability. The context has also been broadened to include other environmental and social stressors, and changes in socioeconomic conditions and sustainable development.

This change in emphasis has led to the development of a second generation of studies that begin with current climate variability and current adaptation (or the lack of adaptation or maladaptation). This empirical approach provides a grounding in reality on which to base projections of future impacts, vulnerability, and adaptation. New methods, frameworks, and guidelines are being developed to facilitate second order studies, including:

- the United Nations Development Programme (UNDP) Adaptation Policy Framework (Burton et al., 2004; see Chapter 2 of this document)
- the National Adaptation Plans of Action (NAPA) Guidelines (UNFCC, 2002; see Chapter 2 of this document)
- the Assessments of Impacts and Adaptations to Climate Change (AIACC) projects (see Chapter 2 of this document).

Much of the work under way includes a blend of first and second generation approaches and tools, and the research approaches are evolving rapidly, as is to be expected in a relatively new area of research and study. The more recent emphasis on current climate variability, and current vulnerability and adaptation, has been associated with more sophisticated approaches to socioeconomic scenarios, to stakeholder participation, to adaptation policies and measures, and to the assessment and strengthening of adaptation capacity. These changes are reflected in the content and structure of this updated version of the compendium, making it more relevant to today's needs. This is not the end of the road, however. As understanding of climate change impacts expands and as social and economic circumstances change, there will be a continued need for new approaches and new research tools and methods. Users of this compendium are thus challenged to go past the role of passive users and to make their own contributions to the improvement of methods and tools.

1.1 Focus and Scope of the Compendium

This updated compendium is organized in a way that allows existing adaptation analysis and decision frameworks and tools to be catalogued in manner that is clear and easy to use and does not prescribe or recommend methods or tools. Whereas the original compendium for the most part organized discrete adaptation decision tools according to sectors of application, echoing the sectoral model based approach to vulnerability and adaptation assessment of the time, the organization of this revised compendium reflects the expanded scope and comprehensiveness of methods currently in use.

Thus, the revised compendium attempts to reflect the current state of knowledge by collecting and summarizing three broad categories of frameworks, methods, and tools. First, it reviews some of the complete frameworks (both what are previously referred to as first generation approaches and second generation approaches), those methods that prescribe an entire process for the assessment of vulnerability and adaptation and in some instances assemble toolkits to support this process. These frameworks offer a broad strategic approach.

Second, the compendium establishes a structure for cataloging tools that assist in addressing key cross-cutting themes or whose application spans multiple steps of the assessment process, as well as discrete tools that are applicable to multiple sectors. These are not comprehensive frameworks, nor are they tools applicable only to a specific sector and step of an assessment framework. Some constitute partial frameworks or particular research orientations that prescribe an approach to undertaking an assessment (e.g., stakeholder analysis) and can be applied at various stages of the assessment. Others are tools that are applicable to more than one sector or tend to address a particular stage of an assessment (e.g., GCM downscaling, socioeconomic scenario building, decision making).

Third, as the first version of the compendium did, this revised version organizes discrete tools specific to particular sectors. Much of the content of the original compendium has been conserved here. We have significantly updated the agriculture sector to reflect the development and use of new methods and tools.

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

The compendium provides users with key information about available frameworks and tools, special features of each framework or tool, and information about how to obtain documentation, training, or publications supporting each tool. It has been designed to be used as a reference document to identify available frameworks and tools for assessing vulnerability and adaptation.

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 and a map to point users to additional sources of information.

Each framework or tool is described in a summary table that summarizes its key features. With these tables as a reference, users can decide which frameworks and tools they want to use and then can obtain further documentation for the listed contact to fully evaluate each option. Each tool has been summarized to identify its potential applications. Looking at 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.

The compendium is not a "cookbook." It does not provide full documentation for frameworks, models, or other tools. Users will need to obtain this information from the providers. Furthermore, users should carefully consider the alternative frameworks and tools discussed in the compendium. The appropriateness and usefulness of each may vary depending on users' circumstances and information needs. Options for analysis should be carefully investigated and considered.

Tables include relevant topics from the following list:

- ***Description.*** Explains the type of framework or 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 required and the processes used to evaluate these data.

- ***Appropriate use.*** Describes where the framework or tool is (and is not) applicable. This gives the user an idea of the stage at which it is appropriate to use.

- ***Scope.*** Covers the fields in which the framework or 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 framework or tool (e.g., a model, a cost-effectiveness evaluation, an organizing framework).

- ***Key input.*** Explains the information or data required to use the framework or tool.

- ***Key tools.*** For frameworks, describes discrete tools that would play an important role in implementing a complete framework.

- ***Ease of use.*** Describes the level of difficulty associated with implementing the framework or tool.
- ***Training required.*** Describes the level of expertise and any specific skills required to use the framework or tool effectively.
- ***Training available.*** Describes the training available to learn how to use the framework or tool effectively.
- ***Computer requirements.*** Describes the computer hardware and software necessary to use the framework or tool.
- ***Documentation.*** Provides the citations for sources describing in detail how to use the framework or tool. Generally this is a user's manual or similar document.
- ***Applications.*** Briefly describes actual cases and projects where the framework or tool has been applied.
- ***Contacts for framework/tools, documentation, technical assistance.*** Provides information on who to contact for further information, documentation, and technical assistance. Generally the agency or firm that developed the framework or 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 framework or tool. Where applicable, gives information on the approximate cost of implementing the framework or tool. Where the exact cost is unavailable, relative cost is used (e.g., high, medium, or low relative to other described).
- ***References.*** Lists the citations for documents, articles, etc., that have critically discussed use of the framework or tool.

Finally, this compendium is part of an ongoing process and should be considered a living document. As the frameworks and tools it describes are used and field tested, they will be steadily improved and their application refined. Furthermore, the compendium is in no way intended to provide a comprehensive listing of approaches, cross-cutting issues, or sectors or of the potential frameworks and tools that might be characterized as such. Rather, the hope is to set up a structure that will accommodate the addition of other tools and frameworks currently in use as well as new approaches that will be developed in the future.

Notes on using the compendium

Summary tables in the compendium provide an overview of the framework or tool in question. They are designed to assist the user in identifying methods and techniques to investigate further. The main function is to direct users how to obtain more information, not to instruct the user on how to apply any particular framework or tool.

Many of the frameworks and tools overlap with one another. They should not be thought of as representing discrete points on a continuum, embodying either-or choices. Users may find that more than one framework or tool might be suited to their goals. It may be that users might benefit from combining elements of different methods or techniques that are profiled here.

The compendium is intended to be a living document. It reflects the state of knowledge at the time it was compiled. Additionally, it provides a structure that should allow it to grow to incorporate new frameworks and tools.

1.2 Organization of the Compendium

Chapters 2, 3, and 4 of the compendium contain the summary tables that describe each framework or tool. Table 1.1 summarizes their organization and lists the frameworks and tools described in the compendium.

Table 1.1. Organization of frameworks and tools in the compendium

Chapter 2: Complete Frameworks and Supporting Toolkits		
	IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations	
	U.S. Country Studies Program (USCSP)	
	UNDP Adaptation Policy Framework (APF)	
	Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC)	
	Guidelines for the Preparation of National Adaptation Programmes of Action (NAPA)	
	United Kingdom Climate Impacts Programme (UKCIP) Climate Adaptation: Risk, Uncertainty and Decision Making	
Chapter 3: Cross-Cutting Issues and Multisector Approaches		
	3.1 Development and Application of Scenarios	
	3.1.1 General tools	
		IPCC-TGCIA Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment

Table 1.1. Organization of frameworks and tools in the compendium (cont.)

3.1.2	Climate downscaling techniques
	Statistical Downscaling
	Statistical Downscaling Model (SDSM)
	Dynamical Downscaling
	MAGICC/SCENGEN
	Weather Generators
3.1.3	Socioeconomic scenarios
	Developing Socioeconomic Scenarios: For Use in Vulnerability and Adaptation Assessments
	Adoption of Existing Socioeconomic Scenarios
	Qualitative and Quantitative Scenarios Emphasizing Stakeholder Input
3.2	Decision Tools
	Policy Exercise
	Benefit-Cost Analysis
	Cost-Effectiveness
	Multicriteria Analysis (MCA)
	Tool for Environmental Assessment and Management (TEAM)
	Adaptation Decision Matrix (ADM)
	Screening of Adaptation Options
3.3	Stakeholder Approaches
	Stakeholder Networks and Institutions
	Scoping
	Vulnerability Indices
	Agent Based Social Simulation
	Livelihood Sensitivity Exercise
	Multistakeholder Processes
	Global Sustainability Scenarios
3.4	Other Multisector Tools
	Climatic Change and Variability (CCAV)
	Expert Judgment
	Historical or Geographic Analogs: Forecasting by Analogy
	Uncertainty and Risk Analysis
	Estimating Adaptation Costs: M-CACES

Table 1.1. Organization of frameworks and tools in the compendium (cont.)

Chapter 4: Sector-Specific Tools

4.1 Agriculture Sector Tools

- APSIM (Agricultural Production Systems sIMulator)
- WOFOST
- ACRU (Agricultural Catchments Research Unit)
- Process Soil and Crop Models: CENTURY
- ORYZA 2000
- Information and Decision Support System for Climate Change Studies in South East South America (IDSS-SESA Climate Change)
- Decision Support Systems Linking Agro-Climatic Indices with GCM-Originated Climate Change Scenarios
- Model of Agricultural Adaptation to Climatic Variation (MAACV)
- Relative Risk Index (RRI)
- Government Support in Agriculture for Losses due to Climatic Variability
- Process Crop Models: International Consortium for Application of Systems Approaches to Agriculture (ICASA) — International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Family of Models
- Process Crop Models: General-Purpose Atmospheric Plant Soil Simulator (GAPS 3.1)
- Process Crop Models: Erosion Productivity Impact Calculator (EPIC)
- Irrigation Model: CROPWAT
- Process Crop Models: Alfalfa 1.4
- Process Crop Models: AFRC-Wheat
- Process Crop Models: RICEMOD
- Process Crop Models: GOSSYM/COMAX
- Process Crop Models: GLYCIM
- Economic Models: Econometric (Ricardian-based) Models
- Economic Models: Input-Output Modeling (with IMPLAN)

4.2 Water Sector Tools

- WaterWare
- Water Evaluation and Planning System (WEAP)
- RiverWare
- Interactive River and Aquifer Simulation (IRAS)
- Aquarius
- RIBASIM
- MIKE BASIN

Table 1.1. Organization of frameworks and tools in the compendium (cont.)

4.3	Coastal Resources Tools
	IPCC Common Methodology
	UNEP Handbook Methodology
	Decision Support Models: COSMO (COastal zone Simulation MOdel)
	The South Pacific Island Methodology (SPIM)
	RamCo and ISLAND MODEL
	Dynamic Interactive Vulnerability Planning (DIVA)
	Shoreline Management Planning (SMP)
4.4	Human Health Sector Tools
	MIASMA (Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)
	Environmental Burden of Disease Assessment
	CIMSiM and DENSiM (Dengue Simulation Model)
	UNFCCC Guidelines: Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change
	LymSiM
	Mapping Malaria Risk in Africa (MARA) Low-end Information Tool (LITe)
4.5	Terrestrial Vegetation Sector Tools
	LPJ (Lund-Postdam-Jena Model)
	IBIS (Integrated BIosphere Simulator)
	Medrush Vegetation Model
	Century
	MC1
	IMAGE (Integrated Model to Assess the Greenhouse Effect)
	AEZ (Agro-ecological Zones) Methodology
	CASA (Carnegie-Ames-Stanford Approach) Model
	TEM (Terrestrial Ecosystem Model)

1.3 Definitions

Methodology /ay /approach: A complete framework that prescribes an entire process for the assessment of vulnerability and adaptation and offers a broad strategic approach. An approach in some instances assembles certain methods and toolkits to support this process. Examples include: IPCC Technical guidelines (1994), NAPAs guidelines (2002), Adaptation Policy Framework (2004).

Method. A set and sequence of steps or tasks that should be followed to accomplish the task that represents a part of large framework. Method can be implemented through using a number of tools. Examples include: Methods for development and use of scenario data in the vulnerability and adaptation assessment, e.g. those presented in the UNEP Handbook (1998) and IPCC-TGCIA Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment (1999).

Tool. A means or instrument by which a specific task is accomplished. Examples include: RCMs, impact models, decision tools (cost-benefit analysis, MCA, TEAM, ADM, etc), stakeholder tools (vulnerability indexes, Livelihood Sensitivity Exercise, etc.).

References

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

Burton, I., S. Huq, and B. Lim. In Preparation. *Adaptation Policy Framework*. United Nations Development Programme, New York.

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.

Feenstra, J., I. Burton, J. B. Smith, and R. Tol (eds.) 1998. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*. Institute for Environmental Studies, Free University, Amsterdam.

Kates, R. W., J. Ausubel, and M. 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.

UNITAR. 2003. *Developing Human and Institutional Capacity to Address Climate Change Issues in LDCs: Preparing for NAPAs*. United Nations Institute for Training and Research. Available at http://www.unitar.org/ccp/LDCreport.pdf.

2. Complete Frameworks and Supporting Toolkits

The complete frameworks and associated toolkits described in this chapter of the compendium, listed in Table 2.1, span a broad range of approaches. The IPCC Technical Guidelines, the UNEP Handbook, and the U.S. Country Studies Program represent examples of first generation approaches to the assessment of vulnerability and adaptation. They have an analytical thrust, and focus on an approach that emphasizes the identification and quantification of impacts. The APF is a second generation assessment and places the assessment of vulnerability at the center of the process. The AIACC approach (technically a collection of projects rather than an explicit framework) incorporates elements of both first generation and second generation assessments. The NAPA Guidelines provide some conceptual and procedural oversight for the process of producing a document that identifies national priorities for adaptation. The UKCIP report provides guidance to those engaged in decision making and policy processes. It lays out an approach to integrating climate adaptation decisions and more generally climate influenced decisions into the broader context of institutional decision making. The UKCIP framework is distinctive in that it casts the assessment process in risk and decision under uncertainty terms.

Table 2.1. Complete frameworks and supporting toolkits
IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations
U.S. Country Studies Program (USCSP)
UNEP Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies
UNDP Adaptation Policy Framework (APF)
Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC)
Guidelines for the preparation of National Adaptation Programmes of Action (NAPA)
United Kingdom Climate Impacts Programme (UKCIP) Climate Adaptation: Risk, Uncertainty and Decision Making

IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations

Description	A set of technical guidelines for the scientist that does not seek to prescribe a single preferred method but rather a range of methods, some of which may be more suitable than others to particular tasks, but which yield comparable results across regions and sectors. The guidelines aid users in assessing the impacts of potential climate change and in evaluating appropriate adaptations. The Guidelines outline a seven step process: (1) definition of the problem, (2) selection of the methods, (3) testing of the methods, (4) selection of the scenarios, (5) assessment of biophysical and socioeconomic impacts, (6) assessment of autonomous adjustments, and (7) evaluation of adaptation strategies. A range of methods is identified at each step.
Appropriate Use	To enable comparable estimates of impacts and adaptations in different sectors or regions.
Scope	All regions and sectors.
Key Output	Most suitable strategies for minimizing the effects of climate change.
Key Input	Depends on existing data, methods that will be used, and the particular objectives of the assessment.
Key Tools	General circulation model scenarios, use of the scenario data in impacts assessment (see Section 3.1) economic models, biophysical models, cost-benefit analysis (see Section 3.2). Please see the UNEP manual for more information on methods used (see summary table in Section 3.1.3). Summary of the methods used under this approach can be found in the first (FCCC/SBI/1999/11), second (FCCC/SBI/2000/15), third (FCCC/SBI/2001/14 and Add.1), fourth (FCCC/SBI/2002/16), and fifth (FCCC/SBI/2003/13) compilations and syntheses of initial national communications from non-Annex I Parties at http://unfccc.int/national_reports/non-annex_i_natcom/compilation_and_synthesis_reports/items/2709.php
Ease of Use	Depends on specific application.
Training Required	Depends on user familiarity with prescribed tools. It is likely that some training is required to complete the seven steps, particularly in using advanced quantitative models and in linking model inputs and outputs.
Training Available	No formal training currently offered though IPCC, though training may be available for particular tools the guidelines prescribe, directly from their source. See also training module of the UNITAR Climate Change Programme at http://www.unitar.org/ccp/.
Computer Requirements	No explicit requirements for employing framework, though use of associated tools will require software and in some cases significant computing resources.
Documentation	Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka. 1994. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. London: Department of Geography, University College London. Also, Parry, M. and T. Carter. 1998. *Climate Impact and Adaptation Assessment: A Guide to the IPCC Approach*. London: Earthscan. Guidelines are available at http://www-cger.nies.go.jp/ or http://www-cger.nies.go.jp/cger-e/e_report/r_index-e.html, or can be obtained from Department of Geography, University College London, 26 Bedford Way, London, WC1H 0AP, United Kingdom.

IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations (cont.)

Applications	U.S. Country Studies (see summary that follows), UNEP Country Studies (Contact Ravi Sharma, ravi.Sharma@unep.org), UNDP National Communications Support Programme (project documents at http://www.undp.org/cc/ and http://www.gefonline.org/), and the UNFCCCC compilations of the INCs at http://unfccc.int/national_reports/non-annex_i_natcom/compilation_and_synthesis_reports/items/2709.php.
Contacts for Framework, Documentation, Technical Assistance	Tim Carter; e-mail: tim.carter@vyh.fi.
Cost	No cost for obtaining documentation of framework. Actual cost of conducting such an assessment can vary widely. A detailed study can cost more than several hundred thousand US dollars, although useful results can be obtained from small-scale studies costing US$50,000-100,000.
References	Benioff, R., S. Guill, and J. Lee (eds.). 1996. *Vulnerability and Adaptation Assessments: An International Guidebook.* Dordrecht, The Netherlands: Kluwer Academic Publishers. Erda, L., W.C. Bolhofer, S. Huq, S. Lenhart, S.K. Mukherjee, J.B. Smith, and J. Wisniewski (eds.) 1996. *Climate Change Vulnerability and Adaptation in Asia and the Pacific*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

U.S. Country Studies Program (USCSP)

Description	The aim of the USCSP (no longer in existence) was to assist developing countries and countries with economies in transition in meeting their obligations under the UNFCCC. Countries participating in the USCSP focused on assessing the vulnerability of their climate sensitive sectors and resources and, to a lesser extent, opportunities for adaptation. The general approach prescribed by the program involved six steps: (1) define scope of assessment process, (2) select scenarios, (3) conduct biophysical and economic impact assessments, (4) integrate impact results, (5) analyze adaptation policies and programs, and (6) document and present results to decision makers. At the center of this process is the evaluation of biophysical effects.
Appropriate Use	Best employed when an analysis of biophysical impacts of climate change (e.g., change in rainfall or crop yields) is the central goal. Relatively simple methods can still be applied when date quality and availability are limited.
Scope	All regions, coastal resources, agriculture, grasslands/livestock, water resources, forestry, human health, fisheries, and wildlife.
Key Output	Climate change impacts and, to limited extent, adaptation options.
Key Input	Climate change and baseline socioeconomic scenarios.
Key Tools	Climate change scenarios (e.g., GCM scenarios), socioeconomic baselines (e.g., $IS92_{a\text{-}f}$), and biophysical impact models (e.g., CLIRUN, Holdridge Life Zone Classification model, CERES-Maize; see appropriate sectoral summary tools in Chapter 4).
Ease of Use	Depends on specific application.
Training Required	Training is required in the use of certain models.
Training Available	Contact Stratus Consulting, P.O. Box 4059, Boulder CO 80302. Tel: +1.303.381.8000; e-mail: jsmith@stratusconsulting.com.
Computer Requirements	Depends on particular models and sectors examined.
Documentation	Benioff, T., Guill, S., and Lee, J. (eds.). 1996. *Vulnerability and Adaptation Assessments: An International Guidebook*, Dordrecht, The Netherlands: Kluwer Academic Publishers.
Applications	49 countries participated, investigating impacts in one or more of eight sectors: coastal resources, agriculture, grasslands/livestock, water resources, forests, fisheries, wildlife, and health.
Contacts for Framework, Documentation, Technical Assistance	Joel Smith, Stratus Consulting Inc., P.O. Box 4059, Boulder, CO 80302, USA; Tel: +1.303.381.8000; e-mail: jsmith@stratusconsulting.com.
Cost	Depends on breadth of assessment.

U.S. Country Studies Program (USCSP) (cont.)

References	USCSP. 1999. *Climate Change: Mitigation, Vulnerability, and Adaptation in Developing Countries*, U.S. Country Studies Program, Washington, DC Smith, J.B., N. Bhatti, G. Menzhulin, R. Benioff, M. Campos, B. Jallow, and F. Rijsberman. 1996. *Adaptation to Climate Change: Assessments and Issues*, Springer-Verlag, New York; Benioff, R., S. Guill, and J. Lee (eds.). 1996. *Vulnerability and Adaptation Assessments: An International Guidebook.* Dordrecht, The Netherlands: Kluwer Academic Publishers; Smith, J.B., Huq, S., Lenhart, S., Mata, L.J., Nemesova, I., Toure, S. 1996. *Vulnerability and Adaptation to Climate Change. Interim Results from the U.S. Country Studies Program.* Kluwer Academic Publishers; Dixon, R.K. 1997. “Forward.” *Climatic Change* 36:1-2; Smith, J.B. and J.K. Lazo. 2001. “A Summary of Climate Change Impact Assessments from the U.S. Country Studies Program.” *Climatic Change* 50:1-29.

UNDP Adaptation Policy Framework (APF)

Description	The APF provides guidance on designing and implementing projects that reduce vulnerability to climate change, by both reducing potential negative impacts and enhancing any beneficial consequences of a changing climate. It seeks to integrate national policy making efforts with a "bottom-up" movement. The framework emphasizes five major principles: adaptation policy and measures are assessed in a developmental context; adaptation to short-term climate variability and extreme events are explicitly included as a step toward reducing vulnerability to long-term change; adaptation occurs at different levels in society, including the local level; the adaptation strategy and the process by which it is implemented are equally important; and building adaptive capacity to cope with current climate is one way of preparing society to better cope with future climate. The APF is a flexible approach in which the following five steps may be used in different combinations according to the amount of available information and the point of entry to the project: (1) defining project scope and design, (2) assessing vulnerability under current climate, (3) characterizing future climate related risks, (4) developing an adaptation strategy, and (5) continuing the adaptation process. The framework focuses on the involvement of stakeholders at all stages.
Appropriate Use	The APF is particularly applicable where the integration of adaptation measures into broader sector specific policies, economic development, poverty reduction objectives, or other policy domains is desirable.
Scope	All sectors, all regions, particularly developing countries.
Key Output	Increased adaptive capacity through prioritized adaptation strategies that can be incorporated into development plans.
Key Input	Depends on the particular application and available information. Stakeholder derived information is a key input at all stages.
Key Tools	Vulnerability mapping, dynamic simulation of sustainable livelihoods, multistakeholder analysis (see Section 3.3), cost-effectiveness, decision trees, multicriteria analysis (see Section 3.2), among others.
Ease of Use	Depends on specific application.
Training Required	Depends on nature of particular application.
Training Available	A User's Guidebook is available on the APF web page (see below). Training will be developed (see UNDP web page).
Computer Requirements	In most cases personal computer is sufficient. Depends on tools employed, however.
Documentation	A User's Guidebook for APF and the technical papers that elaborate the APF can be obtained online at: http://www.undp.org/cc/apf_outline.htm.
Applications	Kenya, Honduras, the Central America (see APF web page, above).
Contacts for Framework, Documentation, Technical Assistance	Bo Lim, Chief Technical Advisor, Capacity Development and Adaptation Cluster, UNDP, New York; Fax: 1.212.906.6998; e-mail: bo.lim@undp.org. Technical assistance on individual steps can be obtained from lead authors of the appropriate technical papers.
Cost	Depends on particular application.

UNDP Adaptation Policy Framework (APF) (cont.)

References	Burton, I., S. Huq, and B. Lim. In Preparation. *Adaptation Policy Framework*. United Nations Development Programme. New York. Burton, I., Huq, S., Lim, B., Pilifosova, O., Schipper, E.L. 2002. *From Impacts Assessment to Adaptation Priorities: the Shapping of Adaptation Policy*. Climate Policy, Amsterdam, Vol.2, 145-159. Also see individual technical papers available on website for references.

Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC)

Description	AIACC is a global initiative to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries. AIACC aims to fill gaps in the current understanding of vulnerability and opportunities for adaptation by funding, training, and mentoring developing country scientists to undertake multisector, multicountry research of priority to developing countries. AIACC takes an approach to assessment that is research driven and focused on building capacity. While it does not prescribe an explicit framework for undertaking vulnerability and adaptation assessments it does offer a toolkit for researchers that is useful in the design of projects, as well as the tenets of a general approach. The toolkit gives also information and links on climate models, agriculture models, water resources, ecosystems models. The AIACC regional studies are diverse in their objectives, scientific methods, and the sectors and systems to be investigated, but they share a common second generation assessment approach that places understanding vulnerability at the center of the assessment, engages stakeholders in the assessment process, and gives priority to strengthening the information base for making decisions about adaptation to climate change.
Appropriate Use	The 24 AIACC studies (funded to date) are best used as a source of lessons concerning the process or elements of the process of assessing vulnerability and adaptation options in particular sectors and regions. The AIACC web page can also be consulted for a listing of tools and methods that might be of use in designing such an assessment.
Scope	All sectors, all regions.
Key Output	Adaptation options to reduce vulnerability and risk.
Key Input	Stakeholder generated information about exposure, vulnerabilities, changes, risks, and driving forces.
Key Tools	Stakeholder analysis, sustainable livelihoods and indicators (see Section 3.3b), decision support systems, multicriteria analysis (see Section 3.2), cost-benefit analysis, among others (see http://sedac.ciesin.columbia.edu/aiacc/toolkit.html).
Ease of Use	Depends on specific application.
Training Required	Depends on design of particular assessment and tools employed.
Training Available	A formal series of workshops (on scenarios and on V&A) has been held for the benefit of project participants with several meetings scheduled for the near future (http://www.aiaccproject.org/meetings/meetings.html). Proceedings of past meetings can provide a useful source of information about AIACC projects and approaches. Mentoring and networking also comprise important components of the process. Regional networks will have the capacity to support continuing investigations and can be an important source of technical support (http://sedac.ciesin.columbia.edu/aiacc/resources/network2.jsp and http://sedac.ciesin.columbia.edu/aiacc/synthesis.html). There are also a newsletter and a "AIACC Working Papers" to present information on the different project. The AIACC Technical Committee provides guidance on project design, assessment methods, scenario development, and use and training to AIACC projects.
Computer Requirements	Depends on design of particular assessment and tools employed.
Documentation	http://www.aiaccproject.org/.

Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC) (cont.)

Applications	Applications across a wide range of regions, countries, sectors, systems, and groups. There is a web-based information network to share information from the AIACC regional assessments (http://sedac.ciesin.columbia.edu/aiacc/, and a synthesis of AIACC projects (http://sedac.ciesin.columbia.edu/aiacc/synthesis.html), see also http://www.aiaccproject.org/aiacc_studies/aiacc_studies.html)
Contacts for Framework, Documentation, Technical Assistance	The project is managed by the AIACC Science Director and Project Coordinator and overseen by the AIACC Implementing Committee. The AIACC Technical Committee, including a Scenarios Advisory Group, provides guidance on project design, assessment methods, scenario development and use, training, and selection of projects. Sara Beresford, AIACC Project Coordinator. Tel: 202.462.2213; e-mail: sberesford@agu.org , Neil Leary, Science Director of AIACC, e-mail: nleary@agu.org, or general inquiries to aiacc@agu.org.
Cost	Depends on design of particular assessment.
References	A listing of AIACC reports and publications can be accessed at: http://www.aiaccproject.org/publications_reports/Pub_Reports.html.

Guidelines for the Preparation of National Adaptation Programmes of Action (NAPA)

Description	NAPA is a programme for least developed countries (LDCs) to address their current and urgent adaptation needs. Countries are required to rank adaptation measures for funding by the LDC Fund and other sources based on such criteria as urgency and cost-effectiveness. The NAPA Guidelines are not in themselves a detailed framework for the assessment of vulnerability and adaptation. Instead, they provide some guidance for the process of compiling a document that specifies priority adaptation actions in the least developed countries. The Guidelines outline some "guiding elements" that inform this process and sketch out a process; however, they fall short of providing a structured framework. The guiding elements imply that the NAPA process should be emphasize 1) a participatory approach involving stakeholders, 2) a multidisciplinary approach, 3) a complementary approach that builds on existing plans and programs, 4) sustainable development, 5) gender equity, 6) a country driven approach, 7) sound environmental management, 8) cost-effectiveness, 9) simplicity, and 10) flexibility based on country specific circumstances. In the NAPA process, much of the work of assessing vulnerability and adaptation is intended to be drawn from existing sources. The Guidelines do stress the importance of conducting a participatory assessment of vulnerability to current climate variability and extreme events as a starting point for assessing increased risk due to climate change.
Appropriate Use	Relatively rapid prioritization of adaptation options.
Scope	All regions and sectors.
Key Output	A document describing priorities for adaptation action, emphasizing especially how these priorities and associated plans for action fit in with a country's development needs, other plans, and multilateral environmental agreements.
Key Input	Results from existing and ongoing assessment of vulnerability and adaptation to both current climate variability and climate change.
Key Tools	Cost-effectiveness analysis, cost benefit analysis, multicriteria analysis, stakeholder methods (see Sections 3.5 and 3.6).
Ease of Use	Relatively straightforward, given reliance on existing studies. Ranking of adaptations may be challenging.
Training Required	Some instruction in the NAPA process is helpful.
Training Available	Four regional workshops devoted to increasing understanding of the NAPA process have recently taken place. Materials from these workshops are available at http://www.unitar.org/ccp/napaworkshops.htm.
Computer Requirements	None.
Documentation	Annotated guidelines at http://unfccc.int/resource/docs/cop7/13a04.pdf#page=7. Special website for LDCs at http://unfccc.int/cooperation_and_support/ldc/items/2666.php
Applications	Ongoing UNDP project on developing NAPAs in about 40 countries (see http://www.undp.org/cc/).

Guidelines for the Preparation of National Adaptation Programmes of Action (NAPA) (cont.)

Contacts for Framework, Documentation, Technical Assistance	General information: Youssef Nassef, UNFCC, Tel: +49.228.815.1416; e-mail: YNassef@unfccc.int. For technical guidance and advice on the preparation and on the implementation strategy of NAPAs, including the identification of possible sources of data and its subsequent application and interpretation, contact the LDC Expert Group (LEG) at http://unfccc.int/cooperation_and_support/ldc/items/2666.php.
Cost	No cost for obtaining Guidelines.
References	United Nations Institute for Training and Research. 2003. *Developing Human and Institutional Capacity to Address Climate Change Issues in LDCs: Preparing for NAPAs*. Available at http://www.unitar.org/ccp/LDCreport.pdf.

United Kingdom Climate Impacts Programme (UKCIP) Climate Adaptation: Risk, Uncertainty and Decision Making

Description	The report proposes a step-wise approach to vulnerability and adaptation assessment in a risk uncertainty decision making framework. The framework and guidance aim to help decision makers and their advisors in identifying important risk factors and to describe the uncertainty associated with each. It aims to help them judge the significance of the climate change risk compared to the other risks they face, so they can work out what adaptation measures are most appropriate. There are questions for the decision maker to apply at each stage, and tools that can be used. The report identifies methods and techniques for risk assessment and forecasting, options appraisal and decision analysis. There are eight stages in the framework: (1) identify problem and objectives, (2) establish decision making criteria, (3) assess risk, (4) identify options, (5) appraise options, (6) make decision, (7) implement decision, and (8) monitor, evaluate, and review. It prescribes a circular process in which feedback and iteration are encouraged, and emphasizes a sequential implementation of adaptation measures.
Appropriate Use	The UKCIP framework is applicable to any decision that is likely to be influenced by climate or made in specific response to climate, barring those related to mitigation. Diverse applications are possible. The methodology is particularly relevant to decision makers (1) who are responsible for areas or sectors that are sensitive to climate change, (2) who are responsible for managing the consequences of present day variability in weather or climate, (3) whose decisions could be vulnerable to assumptions about the risks associated with future climate, (4) who are responsible for commissioning or overseeing technical assessments of climate change vulnerability, impacts and associated adaptation options, or (5) who need to address the robustness of a proposed decision to assumptions associated with the nature of the future climate.
Scope	All regions, all sectors. Written from the UK perspective but applicable internationally.
Key Output	Preferred adaptation options (especially no regret and low regret options) based on evaluation criteria and information regarding optimal timing and extent of implementation. Feedback based on monitoring, evaluation, and review from the implementation of these options is an important output, and becomes a key input in the iterative process.
Key Input	Decision-makers' objectives, benchmark levels of climate risk, multiple climate and nonclimate scenarios, and feedback from already implemented adaptations.
Key Tools	See Appendix 4 of UKCIP Technical Report for complete listing. Includes cost-benefit analysis (see Section 3.2), decision/probability trees, stakeholder analysis (see Section 3.3), focus groups, multicriteria analysis, and simulation gaming, among others.
Ease of Use	Depends on specific application.
Training Required	Depends on user familiarity with prescribed tools. It is likely that some training is required to complete the eight steps.
Training Available	No formal training currently offered, but UKCIP Technical Report provides fairly detailed instruction.
Computer Requirements	No explicit requirements for employing framework, though use of some associated tools will require software (see Appendix 4 of UKCIP Technical Report).
Documentation	Willows, R.I. and R.K. Connell. (eds.). 2003. Climate Adaptation: Risk, Uncertainty and Decision-Making. UKCIP Technical Report. UKCIP, Oxford.

United Kingdom Climate Impacts Programme (UKCIP) Climate Adaptation: Risk, Uncertainty and Decision Making (cont.)

Applications	Most applications to date have been within the UK in the following sectors: land use planning, building and infrastructure construction and operation, water management, and environmental protection. Contact UKCIP's technical director Richenda Connell at Richenda.Connell@ukcip.org.uk for details of applications.
Contacts for Framework, Documentation, Technical Assistance	UK Climate Impacts Programme, Union House, 12-16 St. Michael's Street, Oxford, OX1 2DU, United Kingdom. Tel: +44.1865.432076; e-mail: enquiries@ukcip.org.uk. Copies can be downloaded from http://www.ukcip.org.uk/resources/publications/pub_dets.asp?ID=4.
Cost	No cost to obtain documentation. Cost of implementing framework depends on nature of assessment.
References	Connell, R., Willows, R., Harman, J. and Merrett, S. A framework for climate risk management applied to a UK water resource problem. *Journal of the Chartered Institution of Water and Environmental Management.* Accepted, 2004. Willows, R.I., Reynard, N.S. and Connell, R.K. (2005) A framework for the incorporation of climate risks in routine decision-making and policy. (In prep.). Contact UKCIP's technical director Richenda Connell at Richenda.Connell@ukcip.org.uk for details concerning forthcoming publications.

3. Cross-Cutting Issues and Multisector Approaches

The tools described in the part of the compendium encompass a broad range of applications. Some groups of tools address important cross-cutting themes such as use of climate or socioeconomic scenario data. Others such as decision analysis provide more detail on tools that might be most applicable to a particular step of the vulnerability and adaptation assessment process. Others still, such as stakeholder analysis, encompass not only a set of tools but also, in some instances, a partial framework that prescribes a process or an approach to undertaking several steps of a complete assessment.

3.1 Development and Application of Scenarios

The documents and techniques described in this section of the compendium (see Table 3.1) address the development and use of scenario data in the vulnerability and adaptation assessment process. The IPCC guidelines address this application generally, discussing a wide range of issues related to the application of both climate scenarios and socioeconomic scenarios. The techniques that follow are more specific methods that can be used for downscaling climate data or developing socioeconomic scenarios.

The downscaling techniques described here can be used to produce small-scale climate data of the type often required by impact models and to develop future climate scenarios at local and national scales. Downscaling techniques represent only one particular way of generating climate change scenarios. Some of the techniques detailed here require considerable expertise and experience (e.g., dynamical downscaling), while others are relatively straightforward and easy to use (e.g., MAGICC/SCENGEN, SDSM, and weather generators).

The approaches to socioeconomic scenario construction, also listed in Table 3.1, are all part of larger frameworks. While users might consider employing an approach that is derived from a framework similar to that which they are implementing, the approaches described can be used independently of their parent frameworks. In practice, the process of developing scenarios will depend on the nature of the planned assessment. None of the following approaches provides a “one size fits all” method for developing socioeconomic futures, but should instead be viewed as informing a necessarily ad hoc process.

Table 3.1 Development and application of scenarios

3.1.1 General tools	
	IPCC-TGCIA Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment
3.1.2 Climate downscaling techniques	
	Statistical Downscaling
	Statistical DownScaling Model (SDSM)
	Dynamical Downscaling
	MAGICC/SCENGEN
	Weather generators
	Country Specific Model for Intertemporal Climate (COSMIC2)
	Providing Regional Climates for Impacts Studies (PRECIS)
3.1.3 Socioeconomic scenarios	
	Developing Socioeconomic Scenarios: For Use in Vulnerability and Adaptation Assessments
	Adoption of Existing Socioeconomic Scenarios
	Qualitative and Quantitative Scenarios Emphasizing Stakeholder Input

3.1.1 General tools

IPCC-TGCIA Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment

Description	Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment represent part of an initiative of the IPCC Task Group on Scenarios for Climate Impact Assessment (TGCIA) to improve consistency in the selection, interpretation, and application of scenarios (climate, socioeconomic, and environmental) in climate impact and adaptation assessments. They provide user support for the IPCC Data Distribution Centre, which was established under the Task Group, to make freely available a number of global data sets of baseline and scenario information on climatic, environmental, and socioeconomic conditions. The guidelines have four main objectives: 1) introduce and describe the information and analytical tools being provided by the Data Distribution Center, 2) offer guidance on how to interpret the baseline and scenario data held by the DDC and elsewhere, 3) highlight and illustrate the key steps and procedures commonly required in applying a baseline and scenario data in impact and adaptation assessment, and 4) suggest standards for reporting the results.
Appropriate Use	Scenario data should be applied as part of a greater methodological framework for climate change vulnerability and adaptation assessment (see Chapter 2).
Scope	All regions and sectors.
Key Output	The DDC provides three types of data or information: observed global climate data sets, nonclimatic baseline and scenario information, and results from global climate model experiments.
Key Input	Not applicable.
Key Tools	GCMs, weather generators (see summary table in this section), statistical downscaling (see summary table in this section), high resolution GCM experiments, sensitivity analysis, among others.
Ease of Use	Depends on techniques employed.
Training Required	Depends on guidelines employed.
Training Available	No formal training offered.
Computer Requirements	Depends on how scenarios are applied and in the context of which framework.
Documentation	Available at http://ipcc-ddc.cru.uea.ac.uk/guidelines/guidance.pdf.
Applications	Not applicable.

IPCC-TGCIA Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment (cont.)

Contacts for Framework, Documentation, Technical Assistance	Guidelines: Tim Carter, Finish Environment Institute, Tel: +358.9.40300.315; e-mail: tim.carter@vyh.fi. Data: IPCC Document Distribution Center, http://ipcc-ddc.cru.uea.ac.uk; e-mail: ipcc.ddc@uea.ac.uk. or Dr. Michael Lautenschlager, IPCC DDC Manager, Tel: + 49.404.1173.297; e-mail: lautenschlager@dkrz.de.
Cost	Guidelines and data are provided free of charge.
References	Carter, T.R., M. Hulme, and M. Lal. 1999. *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment.* Task Group on Scenarios for Climate Impact Assessment of the Intergovernmental Panel on Climate Change.

3.1.2 Climate downscaling techniques and regional models

Statistical Downscaling

Description	Downscaling is a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs). Typically, GCMs have a resolution of 150-300 km by 150-300 km. Many impacts models require information at scales of 50 km or less, so some method is needed to estimate the smaller-scale information. Statistical downscaling first derives statistical relationships between observed small-scale (often station level) variables and larger (GCM) scale variables, using either analogue methods (circulation typing), regression analysis, or neural network methods. Future values of the large-scale variables obtained from GCM projections of future climate are then used to drive the statistical relationships and so estimate the smaller-scale details of future climate (see also weather generators).
Appropriate Use	Statistical downscaling may be used whenever impacts models require small-scale data, provide suitable observed data are available to derive the statistical relationships.
Scope	All locations.
Key Output	Small scale information on future climate or climate change (maps, data, etc).
Key Input	Appropriate observed data to calibrate and validate the statistical model(s). GCM data for future climate to drive the model(s).
Ease of Use	Difficult to apply from first principles since it requires access to large data sets and considerable expertise to derive the statistical relationships. User-friendly software to facilitate use is available (see SDSM — Statistical DownScaling Model, on next table).
Training Required	Considerable knowledge and experience is required to work from first principles. Use of packages like SDSM, however, requires relatively little training.
Training Available	A training course for SDSM was held in late 2002, but there are no plans currently for future courses.
Computer Requirements	Personal computer.
Documentation	Numerous publications in the scientific literature. The SDSM package provides a list of the most useful such publications arranged by category.
Applications	Widely applied in many regions and over a range of climate impact sectors. For a specific example, see Wilby et al. (1999) in References below.
Contacts for Framework, Documentation, Technical Assistance	SDSM may be obtained by registering at https://co-public.lboro.ac.uk/cocwd/SDSM/
Cost	SDSM is free.

Statistical Downscaling (cont.)

References	Wilby, R.L. and T.M.L. Wigley. 1997. Downscaling general circulation model output: A review of methods and limitations. *Progress in Physical Geography* 21:530-548. Wilby, R.L., T.M.L. Wigley, D. Conway, P.D. Jones, B.C. Hewitson, J. Main, and D.S. Wilks. 1998. Statistical downscaling of general circulation model output: A comparison of methods. *Water Resources Research* 34:2995-3008. Wilby, R.L., L.E. Hay, and G.H. Leavesley. 1999. A comparison of downscaled and raw GCM output: Implications for climate change scenarios in the San Juan river basin, Colorado. *Journal of Hydrology* 225:67-91. Wilby, R.L. and T.M.L. Wigley. 2000. Downscaling general circulation model output: A reappraisal of methods and limitations. In *Climate Prediction and Agriculture*, M.V.K. Sivakumar (ed.). Proceedings of the START/WMO International Workshop, 27-29 September 1999, Geneva. International START Secretariat, Washington, DC, pp. 39-68.

Statistical DownScaling Model (SDSM)

Description	SDSM is a user-friendly software package designed to implement statistical downscaling methods to produce high-resolution monthly climate information from coarse-resolution climate model (GCM) simulations. The software also uses weather generator methods to produce multiple realizations (ensembles) of synthetic daily weather sequences.
Appropriate Use	SDSM can be used while impact assessments require small-scale climate scenarios, provided quality observational data and daily GCM outputs for large-scale climate variables are available.
Scope	All locations.
Key Output	Site-specific daily scenarios for maximum and minimum temperatures, precipitation, humidity. SDSM also produces a range of statistical parameters such as variances, frequencies of extremes, spell lengths.
Key Input	Quality observed daily data for both local-scale and large-scale climate variables to calibrate and validate the statistical model(s). Daily GCM outputs for large-scale variables for future climate to drive the model(s). The current version (2.3) contains observed data libraries for use in model calibration, and GCM data for making future projections, but only for selected regions (currently Europe and Canada). Later versions will expand these data bases.
Ease of Use	The user-friendly software is largely self explanatory. It comes with comprehensive instructions for use.
Training Required	Requires little training for those familiar with climate science but it requires expert knowledge and reiterated efforts to establish realistic and accurate statistical relationships .
Training Available	There are currently no plans for any training courses.
Computer Requirements	Personal computer.
Documentation	Numerous publications in the scientific literature. User's manual at http://www-staff.lboro.ac.uk/~cocwd/SDSM/ManualSDSM.pdf
Applications	Widely applied in many regions and over a range of climate impact sectors.
Contacts for Framework, Documentation, Technical Assistance	New users can register and download the software package at https://co-public.lboro.ac.uk/cocwd/SDSM/.
Cost	SDSM is free.

Statistical DownScaling Model (SDSM) (cont.)

References	Wilby, R.L., Dawson, C.W. 2001. Using SDSM- A decision support tool for the assessment of regional climate change impacts. User's manual. Environmental and Modelling Software. Wilby, R.L. and Dettinger, M.D. 2000. Streamflow changes in the Sierra Nevada, CA simulated using a statistically downscaled General Circulation Model scenario of climate change. In: McLaren, S.J. and Kniveton, D.R. (Eds.), Linking Climate Change to Land Surface Change, Kluwer Academic Publishers, Netherlands, pp. 99–121. Hassan, H., Aramaki, T., Hanaki, K., Matsuo, T. and Wilby, R.L. 1998. Lake stratification and temperature profiles simulated using downscaled GCM output. Journal of Water Science and Technology, 38, 217–226. Wilby, R.L., Hassan, H. and Hanaki, K. 1998b. Statistical downscaling of hydrometeorological variables using general circulation model output. Journal of Hydrology, 205, 1~19. Conway, D., Wilby, R.L. and Jones, P.D. 1996. Precipitation and air flow indices over the British Isles. Climate Research, 7, 169–183. Jones, P.D., Hulme, M. and Briffa, K.R. 1993. A comparison of Lamb circulation types with an objective classification scheme. International Journal of Climatology, 13, 655–663. Rubinstein, R.Y. 1981. Simulation and the Monte Carlo method. Wiley, New York. Narula, S.C. and Wellington, J.F. 1977. An algorithm for linear regression with minimum sum of absolute errors. Applied Statistics, 26, 106–111.

Dynamical Downscaling

Description	Downscaling is a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs). Typically, GCMs have a resolution of 150-300 km by 150-300 km. Many impacts models require information at scales of 50 km or less, so some method is needed to estimate the smaller-scale information. Dynamical downscaling uses a limited-area, high-resolution model (a regional climate model, or RCM) driven by boundary conditions from a GCM to derive smaller-scale information. RCMs generally have a domain area of 106 to 107 km^2 and a resolution of 20 to 60 km.
Appropriate Use	Dynamical downscaling can be used whenever impacts models require small-scale data.
Scope	All locations.
Key Output	Small-scale information on future climate or climate change.
Key Input	Typically six-hourly, gridpoint GCM data for future climate to drive the RCM.
Ease of Use	Requires considerable expertise in climate modeling — for specialists only.
Training Required	Considerable knowledge and experience required.
Training Available	No specific training courses available.
Computer Requirements	Same computer requirements as a GCM — i.e., high-level supercomputer or massively parallel computer.
Documentation	Numerous publications in the scientific literature.
Applications	Widely applied in many regions and over a range of climate impact sectors. For a specific example, see Hay and Clark (2003) in References below.
Contacts for Framework, Documentation, Technical Assistance	None.
Cost	High. Impractical except for academic or government institutions.
References	Hay, L.E. and M.P. Clark. 2003. Use of statistically and dynamically downscaled atmospheric model output for hydrologic simulations in three mountainous basins in the western United States. *Journal of Hydrology* 282:56-75. Leung, L.R., L.O. Mearns, F. Giorgi, and R.L. Wilby. 2003. Workshop on regional climate research: Needs and opportunities. *Bull. Amer. Met. Soc.* 84:89-95. Giorgi, F., B. Hewitson, J. Christensen, M. Hulme, H. Von Storch, P. Whetton, R. Jones, L. Mearns, and C. Fu. 2001. Regional climate information — Evaluation and projections. In *Climate Change 2001. The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.). Cambridge University Press, Cambridge, UK, pp. 583-638.

MAGICC/SCENGEN

Description	MAGICC/SCENGEN is a user-friendly software package that takes emissions scenarios for greenhouse gases, reactive gases, and sulfur dioxide as input and gives global-mean temperature, sea level rise, and regional climate as output. MAGICC is a coupled gas-cycle/climate model. It has been used in all IPCC reports to produce projections of future global-mean temperature and sea level change, and the present version reproduces the results given in the IPCC Third Assessment Report (TAR). MAGICC can be used to extend results given in the IPCC TAR to other emissions scenarios. SCENGEN is a regionalization algorithm that uses a scaling method to produce climate and climate change information on a 5° latitude by 5° longitude grid. The regional results are based on results from 17 coupled atmosphere-ocean general circulation models (AOGCMs), which can be used individually or in any user-defined combination.
Appropriate Use	Can be used whenever future atmospheric composition, climate or sea level information is needed.
Scope	All locations.
Key Output	MAGICC gives projections of global-mean temperature and sea level change. SCENGEN gives the following regional outputs on a 5° latitude by 5° longitude grid: changes in or absolute values of temperature and precipitation, changes in or absolute values of temperature and precipitation variability, signal-to-noise ratios based on intermodel differences or temporal variability, and probabilities of temperature and precipitation change above a specified threshold. The software also quantifies uncertainties in these outputs.
Key Input	Emissions scenarios for all gases considered in the SRES (Special Report on Emissions Scenarios) scenarios: CO_2, CH_4, N_2O, CO, NOx, VOCs, SO_2, and the primary halocarbons considered by the Kyoto Protocol (including SF6). The user also has control over various climate model and gas-cycle model parameters.
Ease of Use	The user-friendly software is largely self explanatory. It comes with a user manual and a technical manual.
Training Required	Requires little training for those familiar with basic climate science.
Training Available	A training course for an earlier version was held in 2000, but there are no plans currently for future courses.
Computer Requirements	Personal computer.
Documentation	Numerous publications in the scientific literature.
Applications	Widely applied in many regions and over a range of climate impact sectors. See References below.
Contacts for Framework, Documentation, Technical Assistance	The primary developer, Tom Wigley, can be contacted at wigley@ucar.edu. See also: http://www.cru.uea.ac.uk/~mikeh/software and http://www.cgd.ucar.edu/cas/wigley/magicc/index.html
Cost	MAGICC/SCENGEN is free.

MAGICC/SCENGEN (cont.)

References	Santer, B.D., T.M.L. Wigley, M.E. Schlesinger, and J.F.B. Mitchell. 1990. Developing Climate Scenarios from Equilibrium GCM Results. Max-Planck-Institut für Meteorologie Report No. 47, Hamburg, Germany. Wigley, T.M.L. and S.C.B. Raper. 1992. Implications for climate and sea level of revised IPCC emissions scenarios. *Nature* 357:293-300. Wigley, T.M.L. 1993. Balancing the carbon budget. Implications for projections of future carbon dioxide concentration changes. *Tellus* 45B:409-425. Raper, S.C.B., T.M.L. Wigley, and R.A. Warrick. 1996. Global sea level rise: past and future. In *Sea-Level Rise and Coastal Subsidence: Causes, Consequences and Strategies*, J. Milliman and B.U. Haq (eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 11-45. Wigley, T.M.L. and S.C.B. Raper. 2001. Interpretation of high projections for global-mean warming. *Science* 293:451-454. Wigley,T.M.L., Raper,S.C.B., Hulme,M. and Smith,S. 2000. The MAGICC/SCENGEN Climate Scenario Generator: Version 2.4, Technical Manual, Climatic Research Unit, UEA, Norwich, UK, 48pp. Wigley, T.M.L. and S.C.B. Raper. 2002. Reasons for larger warming projections in the IPCC Third Assessment Report. *Journal of Climate* 15:2945-2952. Other information is given in the atmospheric chemistry, climate projections, and sea level chapters of the IPCC TAR Working Group 1 report, Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, D. Xiaosu, and K. Maskell (eds.). 2001. *Climate Change 2001: The Scientific Basis*. Cambridge University Press, New York.

Weather Generators

Description	Weather generators are not, strictly speaking, downscaling techniques, but are often used in conjunction with the techniques outlined in this section. A weather generator is a statistical model used to generate realistic daily sequences of weather variables — precipitation, maximum and minimum temperature, humidity, etc. Such data are often referred to as synthetic data. Usually precipitation sequences are generated first, and other data sequences are derived using statistical relationships between these data and precipitation, with different relationships used for wet and dry days. Precipitation is divided into an occurrence process (i.e., whether the day is wet or dry) modeled as a Markov chain, and an amount process (the amount of precipitation on a wet day) sampled randomly from an appropriate distribution, such as a Gamma distribution. By using different random seeds, a large number of sequences can be generated, all of which have the same statistical properties as the original data used to calibrate the statistical model — akin to realizations from a set of parallel universes. This is a crucial factor in assessing uncertainties associated with the chaotic nature of daily weather variability. The SDSM software has a weather generator component.
Appropriate Use	Weather generators are used whenever impacts models require small-scale data on a daily time scale, provided suitable observed data are available to derive the statistical relationships.
Scope	All locations.
Key Output	Station-level information on future precipitation, maximum and minimum temperatures, humidity, etc.
Key Input	Appropriate observed data to calibrate and validate the statistical model(s). GCM data for future climate to drive the model(s).
Ease of Use	There are a number of weather generator software packages requiring different levels of expertise for their use (see References below). The user-friendly software in SDSM's weather generator component is largely self explanatory and comes with comprehensive instructions for use.
Training Required	Requires little training for those familiar with basic climate science.
Training Available	There are no plans currently for future courses.
Computer Requirements	Personal computer.
Documentation	Numerous publications in the scientific literature. The earliest papers date from the 1960s.
Applications	Widely applied in many regions and over a range of climate impact sectors. See References below.
Contacts for Framework, Documentation, Technical Assistance	New users of SDSM can register at http://www.sdsm.org.uk/.
Cost	SDSM is free.

Weather Generators (cont.)

References	Richardson, C.W. 1981. Stochastic Simulation of daily precipitation, temperature and solar radiation. *Water Resources Research* 17:182-190. Nicks, A.D., L.J. Lane, and G.A. Gander. 1985. Weather generator. In *USDA-Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation*, D.C. Flanagan and M.A. Nearing (eds.). USDA-ARS National Soil Erosion Research Lab. Report No. 10, West Lafayette, IN. Wilby, R.L., Hay, L.E. and G.H. Leavesley. 1999. A comparison of downscaled and raw GCM output: implications for climate change scenarios in the San Juan river basin, Colorado. *Journal of Hydrology* 225:67-91. Wilks, D.S. and R.L. Wilby. 1999. The weather generation game: A review of stochastic weather models. *Progress in Physical Geography* 23:329-357. (See also SDSM.)

COSMIC2 (Country Specific Model for Intertemporal Climate Vers. 2)

Description	The COSMIC2 model provides climate-change impact modellers and policy analysts a flexible system that can produce a full range of dynamic country-specific climate-change scenarios. The need for this type of modeling capability was discussed at the IPCC Asia-Pacific Workshop on Integrated Assessment Models held in Tokyo in 1997. That Workshop aimed at improving communication between experts in a variety of disciplines and policy analysts/policy makers. One goal was to expand the use of integrated-assessment modelling for addressing the potential impacts of climate change in a way that better reflected the experiences of researchers from developing countries. These researchers (and others at universities around the world) may not have access to state-of-the-art transient (General Circulation Model) GCM simulations. The expense of running these supercomputer models limits their availability and ease of use. The COSMIC2 model helps remove this limitation. COSMIC2 can provide easy access to credible climate-change scenarios that are consistent with the state-of-the-art, fully coupled, transient ocean-atmosphere GCM simulations.
Appropriate Use	Can be used for estimating country level climate change. The climate change scenarios can be used in impact, vulnerability, and adaptation assessments.
Scope	Provides country level (158 countries) climate change and sea level rise estimates from 2000 up to 2200 for 28 emission scenarios. These include the initial IPCC stabilization scenarios, SRES, and post-SRES CO2 stabilization scenarios.
***Key Output*.**	Monthly mean temperature and precipitation along with annual global mean temperature change, sea level rise, and equivalent CO2 concentration.
Key Input	The user chooses one of 14 GCM's, the country, one of 28 emission scenarios and various climate model parameters (climate sensitivity, sulphate scenario, and sulphate forcing) along with the terminal year.
Ease of Use	The installation and use assume average competence with personal computers. There is a built-in help facility.
Training Required	Requires some familiarity with climate change literature. IPCC publications would provide all necessary background information.
Training Available	Training courses for an earlier version (COSMIC) were held in various countries under the US Department of Energy Country Studies Program. There currently are no plans for additional courses.
Computer Requirements	Personal computer with Windows XP/2000/9X operating system.
Documentation	Numerous publications in the scientific literature.
Applications	COSMIC is in use by 130 research groups in 50 countries.
Contacts for Framework, Documentation, Technical Assistance	COSMIC2 was developed by: Michael E. Schlesinger, Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, schlesin@atmos.uiuc.edu Larry J. Williams, Global Climate Change Research, Electric Power Research Institute, ljwillia@epri.com
Cost	The software is free. Send request to Larry J. Williams (ljwillia@epri.com)

COSMIC2 (Country Specific Model for Intertemporal Climate Vers. 2) (cont.)

References	Williams, Larry J., Shaw, Daigee, Mendelsohn, Robert: 1998,'Evaluating GCM Output with Impact Models', *Climatic Change*, 39: 111-133. Yohe, Gary and Schlesinger, Michael E.: 1998,'Sea-Level Change: The Expected Economic Cost of Protection or Abandonment in the United States', *Climatic Change*, 38: 337-472. Schlesinger, M.E. and S. Malyshev, 'Changes in near-surface temperatures and sea level for the Post-SRES CO2-stabiliztion scenarios', *Integrated assessment*, 2: 95-110. Schlesinger, M.E., S. Malyshev, E.V. Rozanov, F. Yang, N.G. Andronova, B. de Vries, A. Grübler, K. Jiang, T. Masui, T. Morita, J. Penner, W. Pepper, A. Sankovski and Y. Zhang, '2000: Geographical distributions of temperature change for scenarios of greenhouse gas and sulfur dioxide emissions.', *Tech. Forecast. Soc. Change*, 65, 167-193.

PRECIS (Providing Regional Climates for Impacts Studies) – The Hadley Centre regional climate modeling system

Description	PRECIS is essentially a regional climate modeling system. It is based on the third generation of the Hadley Centre's regional climate model (HadRM3), together with user-friendly data processing and visualization interface. Its flexible design allows for applications in any region of the world. Like any other regional climate models, PRECIS is driven by boundary conditions simulated by General Circulation Models (GCMs). To facilitate the application, boundary conditions simulated by the Hadley Centre GCM experiments forced by four SRES marker scenarios are supplied with the software.
Appropriate Use	PRECIS can be used to generate finer-resolution, physically consistent regional climate projections when General Circulation Model (GCM) outputs are not sufficient to provide regional details as required by V&A assessment.
Scope	Any region in the world (with a minimum area of 5,000km by 5,000 km) given that sufficient observed data are available to validate model outputs
Key Output	(Typically) hourly climate variables at approximately 50 km horizontal resolution
Key Input	Modeling domain, details of the driving GCM experiment, length of integration, specification of output files
Ease of Use	Requires considerable expertise in climate modeling
Training Required	Considerable knowledge and experience required
Training Available	To be discussed with the Hadley Centre
Computer Requirements	A PC running the Linux operating system is required. It should have a minimum specification of a 1GHz processor, 500 Mb of memory, 60 Gb of disk space, and a tape drive to allow offline storage. A PC with a 1.4 GHz Athlon processor takes approximately 4~6 months to carry out a 30-year simulation.
Documentation	A Hadley Centre brochure on PRECIS is available at http://www.met-office.gov.uk/research/hadleycentre/pubs/brochures/B2001/precis.pdf; An information sheet on the status of PRECIS has been prepared and covers aspects such as availability, support and requirements of PRECIS is available at http://www.met-office.gov.uk/research/hadleycentre/models/PRECIS_info1_Feb02.doc
Applications	Regional climate simulations have been performed with PRECIS in India, South Africa, and China.
Contacts for Framework, Documentation, Technical Assistance	The Regional Modelling Group at the Hadley Centre Met Office Hadley Centre FitzRoy Road, Exeter Devon, EX1 3PB United Kingdom Tel.: +44 1344 854938 Fax: +44 1344 854898 Email: précis@metoffice.com
Cost	The software, together with a suite of supporting materials and boundary condition data, are provided free of charge to developing countries and countries with economy in transition. Other users will be expected to cover relevant costs.

3.1.3 Socioeconomic scenarios

Developing Socioeconomic Scenarios: For Use in Vulnerability and Adaptation Assessments

Description	This UNDP manual provides approaches to developing scenarios of the future, both without climate change and with climate change and adaptation. The first part of the guidance is consistent with the IPCC's *Special Report on Emissions Scenarios*: development of qualitative "storylines" of the future and selection of proxy values to represent important elements of socioeconomic conditions, all supplemented by research and quantitative data, as appropriate. The second part of the guidance demonstrates an approach to sectoral scenarios by using quantitative indicators to calculate food security. Moreover, the guidance recommends a stakeholder involvement process.
Appropriate Use	The guidance can be used in analyses of vulnerability and adaptation to climate change at local, sectoral, regional, and national scales. Thus, the scenarios can contribute to developing countries' National Communications, National Adaptation Programmes of Action (NAPAs), and grant proposals to, e.g., the Global Environment Facility (GEF).
Scope	Local, sectoral, regional, and national.
Key Output	A qualitative or qualitative and quantitative description of the social and economic characteristics of a sector or geographical location as they exist currently and may evolve in the future. The descriptions are focused on key variables, called proxy values, that summarize or otherwise simplify relevant information.
Key Input	Qualitative and/or quantitative information on the sector or region of interest.
Ease of Use	Depends on complexity of data gathering and analytic techniques chosen — from rigorous stakeholder input and other qualitative methods to complex, model-based techniques.
Training Required	No training required, unless unfamiliar models are chosen for use.
Training Available	No formal training currently offered.
Computer Requirements	None, unless project teams choose computer-based methods.
Documentation	Developing Socioeconomic Scenarios: For Use in Vulnerability and Adaptation Assessments. May 2001. Available at http://www.undp.org/cc/pdf/publications%20and%20flyers/UNDP%20socioec%20scenario_May.pdf. See also documents at http://www.undp.org/cc/COP9.htm
Applications	Has been piloted in several countries; will be used in conjunction with the UNDP's Adaptation Policy Framework to develop adaptation strategies, policies, and measures (see APF summary table in Chapter 2).
Contacts for Framework, Documentation, Technical Assistance	Bo Lim, Chief Technical Advisor, National Communications Support Programme, UNDP-GEF, Room 1607, 304 East 45th St, NY, NY 10017, USA; Tel: 1.212.906.5730; Fax: 1.212.906.6568; e-mail: bo.lim@undp.org.
Cost	No cost.
References	See Documentation above and APF summary table in Chapter 2.

Adoption of Existing Socioeconomic Scenarios

Description	The UNEP Handbook describes an approach to developing sectoral assessments of impacts and adaptation. In general, analysts are encouraged to use existing scenarios of both socioeconomic conditions and climate change, to integrate them, and to develop adaptation strategies. The definition of socioeconomic includes demographic and economic data, technology, legislation, culture, decision-making processes – "everything that shapes a society." Table 2.1 in the handbook lists relevant variables for each of the sectors covered (water resources, coastal zones, agriculture, human health, energy, forestry, livestock and grasslands, wildlife and biodiversity, and fisheries). Sources for data-based scenarios are given, and using multiple scenarios is recommended. Specific guidance is sparse.
Appropriate Use	The Handbook can be used for analyses of sectoral impacts and adaptation to climate change.
Scope	Local, sectoral, regional, and national. However, sources for existing socioeconomic scenarios are global and regional only, except for the World Bank, which includes countries.
Key Output	Scenarios that are either "borrowed" from the literature or "inspired" by historical trends and geographical analogues.
Key Input	Qualitative and/or quantitative information on the sector of interest.
Ease of Use	Relatively easy, especially if literature sources are used instead of primary data gathering and scenario development.
Training Required	No training required.
Training Available	No formal training currently offered.
Computer Requirements	None, although data may be downloaded from sources such as the World Bank and manipulated by spreadsheet or other computer-based programs.
Documentation	Feenstra, J.F., I. Burton, J.B. Smith, and R.S.J. Tol (eds.). 1998. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*. Version 2.0. Available at http://www.falw.vu.nl/images_upload/151E6515-C473-459C-85C59441A0F3FB49.pdf
Applications	The first phase of the Netherlands Climate Change Study Assistance Programme (NCCSAP) lists 17 countries where socioeconomic scenarios are being or will be developed. The projects' synopses explicitly mention development of climate scenarios and socioeconomic scenarios to be used in the impact and adaptation studies. Information is on http://www.vu.nl/ivm > Projects > NCCSAP-Climate Change Programme. The book 'Climate Change in Developing Countries' mentioned on this site, may be of interest as well.
Contacts for Framework, Documentation, Technical Assistance	Dr. Michiel van Drunen, Institute for Environmental Studies, Vrije Universiteit, Amsterdam; e-mail: michiel.van.drunen@ivm.falw.vu.nl To contact for NCCSAP II see http://nccsapnet.eriya.com
Cost	No cost.
References	See Documentation above.

Qualitative and Quantitative Scenarios Emphasizing Stakeholder Input

Description	The second and third steps of the Adaptation Policy Framework (APF) (see Chapter 2 for a description of the entire framework), assessing current vulnerability and characterizing future climate risks, involve developing socioeconomic scenarios (called "conditions and prospects"). Technical Paper 6 is devoted to guidance on this topic. Users are advised to include indicators (qualitative or quantitative or a mix of both) in five categories: demography, economics, natural resource use, governance/policy, and culture. The baseline should include current adaptations to current climate. Users are then given guidance on constructing storylines of the future and exploring at least two significantly different but possible futures.
Appropriate Use	The guidance on socioeconomic scenarios is designed as part of a larger process of developing adaptation strategies, policies, and measures. Other analyses that interact with socioeconomic scenarios are climate risks and vulnerability analyses. Crosscutting guidance is given on involving stakeholders and increasing adaptive capacity.
Scope	Local, sectoral, regional, and national. The APF will be most useful at the local and sectoral levels.
Key Output	Scenarios that include demographic, economic, governance/policy, and cultural indicators and data.
Key Input	Qualitative and/or quantitative information from various sources, including expert and stakeholder input.
Ease of Use	The whole APF process requires a substantial commitment of time and resources; the scenario portion can be developed using existing data and stakeholder input or more sophisticated methods such as tailored computer-based models.
Training Required	No training required.
Training Available	Formal training is being planned but is not currently offered.
Computer Requirements	None.
Documentation	See http://www.undp.org/cc/pdf/APF/TP%20final/ for the User's Guidebook and the Nine Technical Papers.
Applications	GEF projects in Latin America are being designed using the APF, but it has not yet been employed in the projects.
Contacts for Framework, Documentation, Technical Assistance	Bo Lim, Chief Technical Advisor, National Communications Support Programme, UNDP-GEF, Room 1607, 304 East 45th St, NY, NY 10017, USA; Tel: 1.212.906.5730; Fax: 1.212.906.6568; e-mail: bo.lim@undp.org.
Cost	No cost.
References	See Documentation above.

3.2 Decision Tools

The tools described in this section assist analysts in making choices between adaptation options (Table 3.2). Some of these tools rely on a single monetary metric and focus on a single decision criterion (e.g., benefit-cost analysis, cost-effectiveness). Others enable the user to define and incorporate more than one such decision criterion (e.g., MCA and the three examples of which, TEAM, Adaptation Decision Matrix, and screening of adaptation options, are included in this section). Other tools, of which policy exercise is an example here, seek to inform the larger policy decision questions, taking into account the institutions involved and affected when pursuing given adaptation options.

Table 3.2. Decision tools

Policy Exercise
Benefit-Cost Analysis
Cost-Effectiveness
Multicriteria Analysis (MCA)
Tool for Environmental Assessment and Management (TEAM)
Adaptation Decision Matrix (ADM)
Screening of Adaptation Options

Policy Exercise

Description	A flexible structured method designed to synthesize and assess knowledge from several relevant fields of science for policy purposes directed toward complex, practical management problems. Policy exercise techniques provide an interface between scientists, academics, and policy makers. At the heart of the process are scenario writing ("future histories," emphasizing nonconventional, surprise rich, but still plausible futures) and scenario analyses via the interactive formulation and testing of alternative policies that respond to challenges in the scenario. These scenario based activities typically take place in an organizational setting reflecting the institutional feature of the issues that are addressed.
Appropriate Use	Policy exercise can be used to generate adaptation options or evaluate already identified adaptation options, especially in the early phases of regional adaptation studies when there is a strong need to structure the problem or in later phases to determine if sectoral policy responses might support or undermine each other.
Scope	All regions, all sectors.
Key Output	Scenarios that inform the adaptation decision process and increase understanding of the organizational and institutional setting in which the process is carried out.
Key Input	Views and ideas of representatives from key institutions.
Ease of Use	Depends on participation of experienced facilitators.
Training Required	Little or no training would be required for participants. Facilitators and support staff require specialized training.
Training Available	No formal training offered. Sources of assistance in organizing a policy exercise can be obtained from contact listed below.
Computer Requirements	Use of personal computers may be necessary to support the variety of models that the exercise might employ.
Documentation	Toth, F.L. 1998. Policy exercises: Objectives and design elements. *Simulation and Games* 19:235-255. Toth, F.L. 1998. Policy exercises: Procedures and implementation. *Simulation and Games* 19:256-276.
Applications	Southeast Asia (see References below). The exercises involved senior national-level policy makers and senior analysts exploring policy responses under different climate change and impact scenarios.
Contacts for Framework, Documentation, Technical Assistance	Ferenc Toth, International Atomic Energy Agency, Wagramer Str. 5 P.O. Box 100, A-1400, Vienna, Austria; Tel: +43.1.2600.22787; e-mail: F.L.Toth@iaea.org.
Cost	No cost to obtain documentation and supplementary information. Cost of implementing will depend upon the scope of inquiry.
References	Brewer, G.D. and M. Shubik. 1979. *The War of Game: A Critique of Military Problem Solving*. Harvard University Press, Cambridge, MA. Toth, F.L. 1992a. Policy responses to climate change in Southeast Asia. In *The Regions and Global Warming: Impacts and Response Strategies*, J. Schmandt and J. Clarkson (eds.) Oxford University Press, New York, pp. 304-322. Toth, F.L. 1992b. Policy implications. In *The Potential Socioeconomic Effects of Climate Change in South-East Asia*, M.L. Parr, M. Blantran de Rozari, A.L. Chong, and S. Panich (eds.). United Nations Environment Programme, Nairobi, Kenya, pp. 109-121. Toth, F.L. 1992c. Global change and the cross-cultural transfer of policy games. In *Global Interdependence*. D. Crookall and K. Arai (eds.). Springer, Tokyo, pp. 208-215.

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 Available	Contact Stratus Consulting for more information (see Contacts below).
Computer Requirements	Lotus 1-2-3 or Excel spreadsheet software helpful.
Documentation	The World Bank. Environmental Assessment Sourcebook: Vol. 1. Policies, Procedures, and Cross-Sectoral Issues. Published October 1996 by World Bank ISBN: 0-8213-1843-8 SKU: 11843 Vol. 2. Sectoral Guidelines. Published September 1995 by World Bank ISBN: 0-8213-1844-6 SKU: 11844 Vol. 3.: Guidelines for Environmental Assessment of Energy and Industry Projects. Published December 1994 by World Bank ISBN: 0-8213-1845-4 SKU: 11845 Available at http://publications.worldbank.org/ecommerce/catalog/product-detail?product_id=194213&
Applications	Used to evaluate sea level rise adaptation options in Maine, USA.
Contacts for Tools, Documentation, 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: http://www.stratusconsulting.com/.
Cost	Price of Vol. 1.: $ 22.00. Price of Vol. 2.: $ 30.00. Price of Vol. 3.: $ 22.00. 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, prepared by Hagler Bailly Services, Inc., Boulder, CO, USA.

Cost-Effectiveness

Description	Cost-effectiveness analysis takes a predetermined objective and seeks ways to accomplish it as inexpensively as possible. Unlike cost-benefit analysis, the level of the benefit is treated as an external given, and the objective of the analysis is to minimize the costs associated with the achievement of this specified objective.
Appropriate Use	Cost-effectiveness on the adaptation side might be used when, under different climate change scenarios, a required minimum level of a public good or service (e.g., flood protection) is specified and the option to deliver this good at the lowest cost is sought. Also particularly applicable to those cases where the analyst may be unwilling or unable to monetize the most important policy impact. Cost-effectiveness is generally more applicable for individual project decisions that are applying decision rules or procedures which have already been determined in policy, strategic, or program decisions.
Scope	All regions. Can be difficult to apply to those sectors where the market does not apply a satisfactory measure of value for costs.
Key Output	Ranking of alternatives relative according to cost-effectiveness.
Key Input	Cost data for a specified level of policy outcome.
Ease of Use	Can be a significant undertaking. Valuing nonmarket goods can require knowledge of specialized techniques.
Training Required	Knowledge of economics as well as training in estimating the monetary values of costs, especially nonmarket values.
Training Available	Contact Stratus Consulting for more information (see Contacts below).
Computer Requirements	Personal computer.
Documentation	Boardman, A.E., D.H. Greenberg, A.R. Vining and D.L. Weimer. 1996. *Cost-Benefit Analysis: Concepts and Practice*. Prentice Hall, Upper Saddle River, NJ, USA.
Applications	Analysis of pathways to stabilization. See also UKCIP and APF frameworks in Chapter 2.
Contacts for Framework, Documentation, Technical Assistance	Bob Raucher, Stratus Consulting, P.O. Box 4059, Boulder CO 80306; Tel: +1.303.381.8000; e-mail: braucher@stratusconsulting.com; website: http://www.stratusconsulting.com/
Cost	Method can entail a high cost in terms of time for an economic analyst.
References	Wigley, T.M.L., J. Edmonds, and R. Richels. 1996. Economic and environmental choices in the stabilization of atmospheric CO_2 concentrations. *Nature* 379(6582):240-243. Ha-Duong, M., M. Grubb, and J.C. Hourcade. 1997. Influence of socioeconomic inertia and uncertainty on optimal CO_2 emission abatement. *Nature* 390:270-273. Goulder, L.H. and S.H. Schneider. 1999. Induced technological change and the attractiveness of CO_2 emissions abatement policies. *Resource and Energy Economics* 21:211-253.

Multicriteria Analysis (MCA)

Description	MCA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. In MCA, desirable objectives are specified and corresponding attributes or indicators are identified. The actual measurement of indicators need not be in monetary terms, but are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria. Different environmental and social indicators may be developed side by side with economic costs and benefits. Explicit recognition is given to the fact that a variety of both monetary and nonmonetary objectives may influence policy decisions. MCA provides techniques for comparing and ranking different outcomes, even though a variety of indictors are used. MCA includes a range of related techniques, some of which follow this entry.
Appropriate Use	Multicriteria analysis or multiobjective decision making is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach (such as cost-benefit analysis) falls short, especially where significant environmental and social impacts cannot be assigned monetary values. MCA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria.
Scope	All regions, all sectors.
Key Output	A single most preferred option, ranked options, short list of options for further appraisal, or characterization of acceptable or unacceptable possibilities.
Key Input	Criteria of evaluation as well as relevant metrics for those criteria.
Ease of Use	Depends on the particular MCA tool employed. All rely on the exercise of some expert judgment.
Training Required	Choice and application of appropriate MCA technique require some expertise, but can be acquired fairly easily.
Training Available	The United Kingdom Department for Transport Local Government and the Regions (see Documentation) provides nontechnical descriptions of MCA techniques, potential areas of application, and criteria for choosing between different techniques, and sets out the stages involved in carrying out MCA.
Computer Requirements	Personal computer.
Documentation	DEFRA. 2003. *Use of multi-criteria analysis in air quality policy: A Report* (http://www.defra.gov.uk/environment/airquality/mcda/index.htm). DTLR. 2001. *Multi Criteria Analysis: A Manual.* The internet version is now available at http://www.dtlr.gov.uk/about/multicriteria/index.htm. ETR. 1999. *Review of Technical Guidance on Environmental Appraisal:* A Report by Economics for the Environment Consultancy (http://www.defra.gov.uk/environment/economics/rtgea/8.htm).
Applications	World Commission on Dams. Integrated Decision Making Framework. (http://www.dams.org/report/contents.htm). World Conservation Union Office for West Africa. Sustainable Development Planning Process (http://www.iucn.org/themes/wetlands/). Tyndall Center for Climate Change Research. Framework for Carbon Mitigation Projects (http://www.tyndall.ac.uk/publications/working_papers/wp29.pdf).

Multicriteria Analysis (MCA) (cont.)

Contacts for Framework, Documentation, Technical Assistance	For general information and contact information for sources of assistance for particular tools: Stratus Consulting, P.O. Box 4059, Boulder CO 80306; Tel: +1.303.381.8000; Fax: 303.381.8200; e-mail: jsmith@stratusconsulting.com.
Cost	Depends on particular MCA tool applied, but in general is inexpensive.
References	Hamalainen, R.P. and R. Karjalainen. 1992. Decision support for risk analysis in energy policy. *European Journal of Operational Research* 56:172-183. Jones, M., C. Hope, and R. Hughes. 1990. A multi-attribute value model for the study of UK energy policy. *Journal of the Operational Research Society* 41:919-929. Pearman, A.D., P.J. Mackie, A.D. May, and D. Simon. 1989. The use of multi-criteria techniques to rank highway investment proposals. In *Improving Decision Making in Organisations*, A.G. Lockett and G. Islei (eds.). Springer Verlag, Berlin, pp. 158-165.

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 Available	Contact Susan Herrod-Julius for more information (see Contacts 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	The user's manual can be obtained from Ms Susan Herrod Julius (see the email given below). See also the web site http://cfpub.epa.gov/gcrp (>"data, documents and tools"> "publications and presentations")
Applications	Used in China, Costa Rica, Venezuela, Trinidad, Italy, Egypt, and Malawi.
Contacts for Tools, Documentation, Technical Assistance	Susan Herrod-Julius, 8601D, U.S. EPA Headquarters. Ariel Rios Building, 1200 Pennsylvania Avenue, N.W., Washington, DC 20460; Tel: 202.564.3394; e-mail: herrod-julius.susan@epa.gov.
Cost	Free to obtain documentation.
References	Smith, A., H. Chu, and C. Helman. 1996. Tool for Environmental Assessment and Management: Quick Reference Pamphlet. Decision Focus Incorporated, Washington, DC. Smith, A., H. Chu, and C. Helman. 1996. Documentation of Tool for Environmental Assessment and Management. Decision Focus Incorporated, Washington, DC. Burton, I., J. Smith, and S. Lenhart. 1998. Adaptation to climate change: Theory and assessment. In *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*, J. Feenstra, I. Burton, J. Smith, and R. Tol (eds.). UNEP and Vrije Universiteit Amsterdam, Amsterdam, The Netherlands. Herrod Julius, S. and Scheraga, J.D. The TEAM Model for Evaluating Alternative Adaptation Strategies.

Adaptation Decision Matrix (ADM)

Description	The ADM uses multicriteria assessment techniques to evaluate the relative effectiveness and costs of adaptation options. Users are asked to specify criteria that will be used to evaluate options and weight the criteria. Scenarios of current climate and climate change can also be used. Users are asked to give a score (e.g., 0 to 5) on how well each criterion is met under a particular scenario for each option. The scoring can be based on detailed analysis or expert judgment. Scores can be multiplied by weights and summed up to estimate which options best meet the criteria. The scores can be compared to relative costs to assess cost-effectiveness.
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 Available	Contact Stratus Consulting for more information (see Contacts 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. USCSP. 1999. *Climate Change: Mitigation, Vulnerability, and Adaptation in Developing Countries*, U.S. Country Studies Program, Washington, DC
Applications	Used by participants in the U.S. Country Studies and UNEP assistance programs (e.g., Kazakhstan, Cameroon, Uruguay, Bolivia, Antigua, Estonia, Pakistan and Barbuda).
Contacts for Tools, Documentation, 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: http://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. 1999. An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. *Mitigation and Adaptation Strategies for Global Climate Change* 4:25-41.

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? 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.
Ease of Use	Depends on specific application.
Training Required	Requires background knowledge of both the options and the climate change issue being addressed.
Training Available	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*. U.S. Country Studies Program, Washington, DC. USCSP. 1999. *Climate Change: Mitigation, Vulnerability, and Adaptation in Developing Countries*, U.S. Country Studies Program, Washington, DC
Applications	Used by several participants in the U.S. Country Studies and UNEP assistance programs (e.g., Kazakhstan, Cameroon, Uruguay, Bolivia, Antigua, Barbuda, Estonia, and Pakistan).
Contacts for Tools, Documentation, 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: http://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. 1999. An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. *Mitigation and Adaptation Strategies for Global Climate Change* 4:25-41.

3.3 Stakeholder Approaches

Stakeholder approaches in general emphasize the importance of ensuring that the decisions to be analyzed, how they are analyzed, and the actions taken as a result of this analysis are driven by those who are affected by climate change and those who would be involved in the implementation of adaptations. The stakeholder approaches described in this compendium, listed in Table 3.3, represent a way of analyzing the institutional and organization context of the adaptation strategy planning process more than they do specific tools to be applied to an assessment. Application of the stakeholder network and institution approach might well employ a variety of tools, some of which are listed below. The vulnerability indices approach aims to provide the user with a metric for vulnerability and adaptive capacity, but again, its application would most likely rely on other tools. Agent based social simulation is a modeling approach to stakeholder networks and institutions and might in practice take different forms, depending on the user's aims. Livelihood sensitivity exercise is a means of integrating existing knowledge of climate vulnerability with livelihood analysis. Multistakeholder processes are tools emphasizing dialogue on consensus building, and might well be employed as part of the aforementioned approaches. Scoping, which can be used as the first step of a vulnerability and adaptation assessment, allows users to identify tools and approaches that might be applicable to their particular focus. Global sustainability scenarios can provide insight into future vulnerability and adaptive capacity and their associated quantitative indices might typically serve as an input for other approaches described in this section. All of these approaches are relatively new, at least in their application to the climate change problem, and consequently their methods are still being refined.

Table 3.3 Stakeholder approaches
Stakeholder Networks and Institutions
Scoping
Vulnerability Indices
Agent Based Social Simulation
Livelihood Sensitivity Exercise
Multistakeholder Processes
Global Sustainability Scenarios

Stakeholder Networks and Institutions

Description	The stakeholder networks and institutions approach focuses on understanding those who make the decisions and how they relate to one another. Building adaptive capacity over long time scales depends on understanding these relationships. Institutions can be viewed as the collective rules, norms, and shared strategies that define stakeholder behavior. This approach posits that understanding present capacity is key to predicting how it is likely to evolve in response to future risks. These relationships can be complex, and unraveling them can require the use of a number of tools (see below). Each stakeholder has different objectives, resources, and responsibilities, all of which must be investigated. Some stakeholders may have little voice in the process or may be assigned responsibilities in only part of the issue. New stakeholders may emerge and relationships may alter, particularly in a crisis.
Appropriate Use	Useful in determining the present adaptive capacity and how that capacity might be developed in the future. In general stakeholder approaches are oriented toward research teams that support policy making. They help set the framework for evaluating specific measures, and thus from an early part of the decision process, as well as helping to monitor capability over a longer term.
Scope	Global, but most appropriate at national or local level.
Key Output	Characterization of stakeholders and institutions in terms of levels of participation, positions, and boundaries in policy making. Insight into institutional capacity to adapt.
Key Input	A mixture of quantitative and qualitative data depending on actual tools employed in the approach.
Ease of Use	Varies, but application of some tools requires specialist training in policy analysis. Some can be readily adopted by practitioners.
Training Required	Some training is useful, but expertise in policy analysis is more important than specific analytical techniques.
Training Available	Many training courses on stakeholder engagement exist, such as The Environment Council. The EC FIRMA project (http://firma.cfpm.org/) produced a training course in agent based, participatory integrated assessment that includes useful material on stakeholder analysis.
Computer Requirements	Varies.
Documentation	Working papers on institutions, institutional analysis, stakeholders, and case studies in England, The Netherlands and Spain are available or forthcoming on the Societal and Institutional Responses to Climate Change and Climatic Hazards web site. http:// http://firma.cfpm.org/ and http://www.geo.ucl.ac.be/LUCC/research/endorsed/01-sirch/SIRCH.HTML.
Applications	The SIRCH project has evaluated stakeholders and institutions in the context of changing risk of drought and floods.
Contacts for Framework, Documentation, Technical Assistance	Dr. Thomas Downing, Stockholm Environment Institute, Oxford Office, 10B Littlegate Street, Oxford, OX1 1QT, United Kingdom; Tel: +44.1865.202070; e-mail: tom.downing@sei.se.
Cost	No cost.

Stakeholder Networks and Institutions (cont.)

References	See Documentation above.

Scoping

Description	A major step in designing an assessment of climate impacts, vulnerability, and adaptation is to scope the elements of the study. A spreadsheet has been developed to aid project teams in the scoping phase. The spreadsheet has a list of potential methods — over 70 general techniques that are appropriate in various stages of an assessment. A simple form allows users to choose answers to eight scoping questions. The answers are then used to screen the choice of potentially useful tools. A section of the spreadsheet has common flowcharts of projects (e.g., NAPA and APF) and a set of building blocks that users can link to make their own project diagram.
Appropriate Use	This tool can underpin a project design team or be used to backstop a participatory exercise where teams are required to prepare a poster of their project and explain the overall logic and steps to other teams.
Scope	Global.
Key Output	Project design and inventory of tools.
Key Input	Review and synthesis existing information on vulnerability and adaptation, existing development policies and priorities, adaptation needs and constraints, and a list of potential methods.
Ease of Use	Very simple, all data are in the spreadsheet if users wish to change any assumption.
Training Required	None necessary.
Training available	SEI has used this tool to backstop participatory design exercises.
Computer Requirements	PC Windows with Excel (macro functions work with more recent versions).
Documentation	Contained in the spreadsheet; see also the APF scoping technical paper (TP1).
Applications	Flexible use in project design.
Contacts for Framework, Documentation, Technical Assistance	Dr. Thomas Downing, Stockholm Environment Institute, Oxford Office, 10B Littlegate Street, Oxford, OX1 1QT, United Kingdom. Tel: +44.1865.202070; e-mail: tom.downing@sei.se.
Cost	Free, available on the www.vulnerabilitynet.org web site.
References	Downing, T.E. 2003. Scoping Tool for Climate Change Assessment: An Excel Spreadsheet and Toolkit. Stockholm Environment Institute, Oxford, UK.

Vulnerability Indices

Description	Formal vulnerability indices can be helpful as part of an adaptation strategy. Vulnerability is defined by the IPCC as the combination of sensitivity to climatic variations, the probability of adverse climate change, and adaptive capacity. For each of these components of vulnerability, formal indices can be constructed and combined. Methods of aggregating across sectors and scales have been developed in other contexts (e.g., the Human Development Index) and are beginning to be applied to climate change. However, substantial methodological challenges remain — in particular estimating the risk of adverse climate change impacts and interpreting relative vulnerability across diverse situations.
Appropriate Use	They can help identify and target vulnerable regions, sectors or populations, raise awareness, and be part of a monitoring strategy. In general stakeholder approaches are oriented toward research teams that support policy making. They help set the framework for evaluating specific measures, and thus from an early part of the decision process, as well as helping to monitor capability over a longer term.
Scope	Global, but most appropriate at national or local level.
Key Output	Matrices of vulnerability indexes, vulnerability maps.
Key Input	A mixture of quantitative and qualitative data depending on actual tools employed in the approach. Examples of vulnerability indices are commonly available, including the Southeast Asia Environmental Framework (contact Vikrom Mathur at the SEI: www.sei.se) and food security scenarios for South Africa and India (contact Tom Downing at the SEI).
Ease of Use	Varies, but application of some tools requires specialist training in policy analysis. Some can be readily adopted by practitioners.
Training Required	Some training is useful, but expertise in policy analysis is more important than specific analytical techniques.
Training Available	A number of groups offer training in vulnerability assessment particularly related to disasters. The Vulnerability Network led by the SEI maintains a web site with discussion forums, a document hotel, and bibliographies: see www.vulnerabilitynet.org.
Computer Requirements	Varies.
Documentation	UNEP has sponsored a project to review formal vulnerability indices and a background paper has been prepared. A summary of the key issues is available as a PowerPoint presentation on the ECI website (see publications at http://www.eci.ox.ac.uk/). See also the Technical Paper 3 of the Adaptation Policy Framework at http://www.undp.org/cc/apf_outline.htm.
Applications	Vulnerability indices have been used by the Bangladesh Centre for Advanced Studies in Dhaka, South Pacific Applied Geoscience Commission, Association of Small Island States, and Battelle Pacific Northwest Laboratory. The Potsdam Institute for Climate Impact Research has developed an analogous approach on environmental syndromes.
Contacts for Framework, Documentation, Technical Assistance	Dr. Thomas Downing, Stockholm Environment Institute, Oxford Office, 10B Littlegate Street, Oxford, OX1 1QT, United Kingdom. Tel: +.44.1865.202070, e-mail: tom.downing@sei.se. Dr. Antoinette Brenkert, Pacific Northwest National Laboratory, Joint Global Change Research Institute at the University of Maryland, 8400 Baltimore Avenue, Suite 201, College Park, MD 20740-2496, USA; Tel: +1.301.314.6759; Fax: +1.301.314.6760; e-mail: Antoinette.Brenkert@pnl.gov.

Vulnerability Indices (cont.)

Cost	No cost.
References	Downing, T. *et al.* 2001. *Vulnerability indices. Climate Change Impacts and Adaptation*. UNEP, Policy Series 3: 91 pp. (available at http://www.sei.e-collaboration.co.uk/OPMS/view.php?site=seiproject&bn=seiproject_hotel&key=1097073874)

Agent Based Social Simulation

Description	A computer assisted technique for knowledge elicitation assists in building rules of how people respond to a variety of stimuli and scenarios of environmental and social conditions. Agent based social simulation is a relatively formal approach to stakeholder and institutional analysis. It is a computer programming method that uses software agents to represent the positions, boundaries, and actions of stakeholders. This approach is one of the few means to realistically simulate the behavior of stakeholder networks in the context of the rules, norms, and shared strategies from social and economic institutions. This approach can be applied at various stages of an assessment. One example is that agent based social simulation can incorporate socioeconomic scenarios that are constructed as sets of rules regarding, for example, environmental values, regulation, and economic goals. An advantage of this approach is that the realization of socioeconomic scenarios is the outcome of stakeholder behavior rather than being exogenously imposed in a way that bears little relation to actual decision making processes.
Appropriate Use	Applicable to various stages of the design of a strategy to respond to climate change and its subsequent implementation in specific measures.
Scope	Global, but most appropriate at national or local level.
Key Output	Insight into how the decision making and implementation processes. For example, realistic socioeconomic pathways constructed as the outcome of multiple decisions.
Key Input	A mixture of qualitative and quantitative data.
Ease of Use	Varies, though constructing an agent based social simulation model would require significant expertise.
Training Required	Some training is useful, but expertise in policy analysis is more important than specific analytical techniques when it comes to using and interpreting results of agent based social simulation.
Training Available	Very little experience has been gained regarding these approaches to date, and hence no formal training or certification is available. However, occasional workshops are offered. See documentation section below.
Computer Requirements	Personal computer.
Documentation	Center for Policy Modeling at Manchester Metropolitan University is one of the world leaders in agent based social simulation. The CPM developed a user friendly software package (SDML) to facilitate model development. http://cfpm.org/ and http://firma.cfpm.org/.
Applications	Agent based social simulation is only beginning to be applied to climate change. Oxford University's Environmental Change Unit is collaborating with the CPM on various applications to integrated assessment of climate policy. Also, the Carnegie Mellon global change program has elements of agent behavior in the Integrated Climate Assessment Model. A European Union project on integrated water resource management (Freshwater Integrated Resource Management Agents, coordinated by the University of Surrey) will develop agent based approaches further.
Contacts for Framework, Documentation, Technical Assistance	Dr. Thomas Downing, Stockholm Environment Institute, Oxford Office, 10B Littlegate Street, Oxford, OX1 1QT, United Kingdom; Tel: +44.1865.202070; e-mail: tom.downing@sei.se.

Agent Based Social Simulation (cont.)

Cost	No cost.
References	West, J.J. and H. Dowlatabadi. 1999. On assessing the economic impacts of sea-level rise on developed coasts. In *Climate Change and Risk*, T.E. Downing, A.A. Olsthoorn, and R.S.J. Tol (eds.). Routledge, New York, pp. 205-220.

Livelihood Sensitivity Exercise

Description	Livelihood sensitivity mapping exercise is a means of integrating existing knowledge of climate vulnerability with livelihood analysis. It commonly involves stakeholder participation. Initially the exercise can be conducted in the context of rapid workshop breakout group, but eventually can be formalized via the inclusion of expert analysis, impact models, or historical analogues: The exercise involves developing a matrix with three blocks of rows — beginning with ecosystem services (e.g., soil moisture), then livelihood activities (such as crop production) and finally a synthesis based on livelihoods themselves. Climatic stresses (e.g., drought) are listed as columns. Users then fill in the cells — rating the sensitivity of ecosystem services, activities and livelihoods to a range of hazards and stresses. Exposure across the hazards and impacts across the services/activities/livelihoods can be calculated as aggregated indices.
Appropriate Use	Livelihood sensitivity exercise is a useful tool for helping identify vulnerable livelihoods and consequently targeting adaptations that aim to increase the resiliency of particular livelihood strategies to climate change. Livelihood sensitivity exercise is best applied to a single sector or region at any one time. The approach has been used in regional training workshops for the NAPA teams.
Scope	All sectors. Most applicable at a local or regional level.
Key Output	Ranking of vulnerable livelihoods as well as an overall livelihood sensitivity index.
Key Input	Qualitative assessments of sensitivity of livelihoods to climatic threats.
Ease of Use	Easy.
Training Required	A familiarity with livelihoods, expert knowledge elicitation, and vulnerability indicators is helpful.
Training Available	The NAPA workshops have produced a range of presentations and a sample spreadsheet that are available at http://www.unitar.org/ccp/ and www.vulnerabilitynet.org. The spreadsheet includes notes on delineation of livelihoods and an illustrative example based on agriculture in southern Africa.
Computer Requirements	Minimal to none.
Documentation	Available at www.vulnerabilitynet.org.
Applications	See www.livelihood.org.
Contacts for Framework, Documentation, Technical Assistance	Dr. Thomas Downing, Stockholm Environment Institute, Oxford Office, 10B Littlegate Street, Oxford, OX1 1QT, United Kingdom; Tel: +44.1865.202070; e-mail: tom.downing@sei.se.
Cost	Free.
References	See www.livelihood.org. Downing, T.E. 2003. *Livelihood Sensitivity to Climatic Hazards. Annex to Technical Paper 3 of the Adaptation Planning Framework*. SEI, Oxford, UK.

Multistakeholder Processes

Description	The aim of multistakeholder processes are to promote better decision making by ensuring that the views of the main actors concerned about a particular decision are heard and integrated at all stages through dialogue and consensus building. The process takes the view that everyone involved in the process has a valid view and relevant knowledge and experience to bring to the decision making. The approach aims to create trust between the actors and solutions that provide mutual benefits (win-win). The approach is people-centered and everyone involved takes responsibility for the outcome. Because of the inclusive and participatory approaches used, stakeholders have a greater sense of ownership for decisions made. They are thus more likely to comply with them.
Appropriate Use	For decisions that require cooperation between many different stakeholders, where a decision made by one group alone might not be complied with by the other groups. They are suitable for situations where dialogue between the different actors is possible and there is willingness to listen to and learn from others to reconcile different interests and reach consensus solutions. There is no one set approach. The exact nature of a given process will depend on the issues to be covered, the specific objectives, the expertise available, the participants, and the time and other resources available.
Scope	Global, national, and local. Can be used with a wide range of structures and levels of engagement.
Key Output	Transparent and inclusive decision making, strengthened stakeholder networks.
Key Input	Expertise in facilitation, willingness of participants to learn, time to allow trust building, quantitative and qualitative information (depending on tools used), participation of key actors.
Ease of Use	The approach as well as the techniques used are based on common sense. Good planning is a vital part of ensuring a successful outcome and time must be allowed for the design stage of the process.
Training Required	There are a number of good texts available, but additional appropriate training would be beneficial (depending on time, resources, type of process). Need also to design the process to fit the specific needs and circumstances.
Training Available	This is still a new and evolving field. Much experience of using participatory processes at the local level is available but less at national and global levels. Some guidance on approaches is available (see Applications below for examples).
Computer Requirements	Depends on the process.
Documentation	For information about running stakeholder engagement processes: Multistakeholder processes for governance and sustainability, Minu Hemmati, (2002), Earthscan, London. http://www.earthscan.co.uk/.
Applications	Multistakeholder processes have been used in the Aarhus Convention Process, the Bejing+5 Global Forum Online discussions, United Nations sustainable development multistakeholder dialogue, the Environment Council/Shell — Brent Spar Project (see Hemmati above for more information on these) and the Adaptation Policy Framework (APF) (http://www.undp.org/cc/apf_outline.htm).

Multistakeholder Processes (cont.)

Contacts for Framework, Documentation, Technical Assistance	Dr. Kate Lonsdale, Stockholm Environment Institute, Oxford, OX1 1QT; e-mail: kate.lonsdale@sei.se; Dr. Bo Lim, Chief Technical Advisor, National Communications Support Programme, UNDP-GEF, Room 1607, 304 East 45th St, NY 10017, USA; e-mail: bo.lim@undp.org.
Cost	Depends on the scale of the process.
References	Participatory Workshops: A Source Book of 21 Sets of Ideas and Activities, R. Chambers, Earthscan. 2002. Available from http://www.earthscan.co.uk/. Good source book of information about how to run workshops including lots of practical advice and common mistakes. Participatory Learning and Action: A Trainers Guide. J.N. Pretty, I. Guijt, I. Scoones, and J. Thompson, International Institute for Environment and Development (IIED). 1995. Available from www.earthprint.com. A valuable collection of advice, tips, and methods for participatory approaches. The focus is mostly on participatory rural appraisal but much would also be relevant for APF workshops. Enhancing Ownership and Sustainability: A Resource Book on Participation. International Fund for Agricultural Development (IFAD), Coalition for Agrarian Reform and Rural Development (ANGOC) and International Institute of Rural Reconstruction (IIRR). 2001. e-mail: publications@iirr.org. A collection of short reviews of participatory approaches and experience. Facilitator's Guide to Participatory Decision-Making, S. Kaner, L. Lind, C. Toldi, S. Fisk, and D. Berger. 1996. New Society Publishers. A useful introduction to how to build consensus and make sustainable agreements with groups. Also gives advice on how to handle difficult group dynamics and individuals.

Global Sustainability Scenarios

Description	Scenarios of future vulnerability are poorly framed by existing scenarios developed for bracketing future greenhouse gas emissions. Alternative scenarios of sustainability have been developed in various forms, and these correspond to many of the conditions of vulnerability and adaptive capacity that are of concern to development planners and practitioners. A major suite of sustainability scenarios was developed by the Global Scenarios Group (GSG). These include a conventional wisdom of market forces, a world of increasing degradation and impoverishment, and a sustainability transition. They are similar to scenarios developed for the UNEP Geo assessment. The GSG suite of scenarios include storylines and quantified indicators for major world regions using the PoleStar scenario tool developed by SEI-Boston.
Appropriate Use	The GSG and PoleStar data can be used to frame national or local scenarios of vulnerability, or to place national development scenarios in context.
Scope	Global to regional; with some extensions they can be used to frame more local scenarios.
Key Output	Quantitative indicators of environmental change, economic conditions, and social welfare that can be linked to climatic vulnerability.
Key Input	The storylines and overview are described in an SEI monograph, Great Transitions (see References below).
Ease of Use	Very little effort is required to appreciate the storylines. PoleStar is not a simple model to understand, although it is well documented. It may take several days to extract the quantitative data and format for specific purposes; it is possible to create new subregions within PoleStar, but that will require additional time and possibly training.
Training Required	None necessary, although further training in PoleStar may be warranted.
Training available	SEI has used this tool in many contexts — contact SEI-Boston for training in PoleStar and the GSG scenarios; SEI Oxford has developed explicit links to climate vulnerability using South Africa and India as examples.
Computer Requirements	PC Windows.
Documentation	GSG web site, monograph and PoleStar software and manual are available through the SEI Boston office: see www.sei.se.
Applications	Global to local socioeconomic scenarios of future climate vulnerability and adaptive capacity.
Contacts for Framework, Documentation, Technical Assistance	Paul Raskin, SEI-Boston for the GSG and PoleStar, 11 Arlington Street, Boston, MA 02116-3411, USA; Tel: +1.617.266.8090; e-mail: praskin@tellus.org. For application to climate change: Dr. Thomas Downing, Stockholm Environment Institute, Oxford Office, 10B Littlegate Street, Oxford, OX1 1QT, United Kingdom; Tel: +44.1865.202070; e-mail: tom.downing@sei.se.
Cost	PoleStar is available for free in a demonstration version, which includes the GSG scenarios. The GSG monograph is available free in an electronic version.
References	P. Raskin, et al. 2002. Great Transitions. Stockholm Environment Institute, Boston. . Downloadable at http://www.tellus.org/seib/publications

3.4 Other Multisector Tools

The tools described in this part of the compendium, listed in Table 3.4, are applicable to more than one sector. They provide a general evaluation of adaptation options, are easily adapted to numerous regions and situations, and are frequently used in conjunction with sector-specific tools to develop a comprehensive analysis or in support of a complete framework. Some are focused and produce specific information (e.g., M-CACES provides the user with estimates of the cost of particular adaptations, while CCAV provides insight into impacts of climate variability). Others are more general approaches that can be applied to more than one step of a vulnerability and adaptation assessment (e.g., uncertainty and risk analysis, forecasting by analogy, expert judgment).

Table 3.4. Other multisector tools
Climatic Change and Variability (CCAV)
Expert Judgment
Historical or Geographic Analogs: Forecasting by Analogy
Uncertainty and Risk Analysis
Estimating Adaptation Costs: M-CACES

Climatic Change and Variability (CCAV)

Description	A methodology of descriptive statistics to illustrate the changing average conditions and the variability in conditions over time. Climate time-series data can be described according to their average conditions, but of particular importance for vulnerability are the impacts of adaptation to the variability of conditions from year to year. Within the range of climatic conditions is a range of conditions with which humans can cope. This range can be changed with adaptive responses. The climatic conditions can also be described and compared according to the variation of conditions over a particular time period (indicated by the variance).
Appropriate Use	To assess climate change and variability in the context of the coping capacity of human systems.
Scope	All locations; all levels of analysis.
Key Output	Allows user to understand changes not only in average climate conditions but also in extreme conditions.
Key Input	Climate time-series data.
Ease of Use	Easy.
Training Required	No formal training required, although an understanding of climatic data and descriptive statistics is an asset.
Training Available	None identified.
Computer Requirements	None identified.
Documentation	Smit, B. 1999. Agricultural Adaptation to Climate Change in Canada. A Report to the Adaptation Liaison Office. Smit, B., D. McNabb, and J. Smithers. 1996. Agricultural adaptation to climatic variation. *Climatic Change* 33:7-29. Smit, B., I. Burton, R.J.T. Klein, and J. Wandel. 2000. An anatomy of adaptation to climate change and variability. *Climatic Change* 45(1):223-251. Smit, B., I. Burton, R.J.T. Klein, and R. Street. 1999. The science of adaptation: A framework for assessment. *Mitigation and Adaptation Strategies for Global Change* 4(3-4):239-252.
Applications	Applied by Environment Canada's Environmental Adaptation Research Group, and in other climate change and variability research in Canada and Germany.
Contacts for Framework, Documentation, Technical Assistance	Elizabeth Harvey, University of Guelph, Department of Geography, Guelph, ON N1G 2W1; Tel: 519.824.4120 ext. 8961; Fax: 519.837.2940; e-mail: eharvey@uoguelph.ca. Dr. Barry Smit, University of Guelph, Department of Geography, Guelph, ON N1G 2W1 Canada; Tel: 519.824.4120 ext. 3279; Fax: 519.837.2940; e-mail: bsmit@uoguelph.ca. Ian Burton, Environmental Adaptation Research Group, Institute for Environmental Studies, Earth Sciences Centre, 33 Willcocks Street, Suite 1016, University of Toronto, Toronto, ON M5S 1A1.
Cost	None identified.
References	See Documentation above.

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 Available	Informal training offered; contact Ian Burton (see below) for information.
Computer Requirements	None.
Documentation	Not applicable.
Applications	UK, Mackenzie Basin in Canada, Finland.
Contacts for Tools, Documentation, Technical Assistance	Ian Burton, Environmental Adaptation Research Group, Institute for Environmental Studies, Earth Sciences Centre, 33 Willcocks Street, Suite 1016, University of Toronto, Toronto, ON M5S 1A1.
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, U.S. EPA, Washington, DC. Cohen, S.J. (ed.). 1997. Mackenzie Basin Impact Study. No. En 50_118/1997_IE. Environment Canada, Downsview, Ontario.

Historical or Geographic Analogs: Forecasting by Analogy

Description	This qualitative tool is a method for evaluating the effectiveness of potential adaptation strategies by comparing observed adaptations to past climate extremes in different geographic locations, sectors, or time periods. This method compares 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. This approach has not seen extensive use recently.
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 multidisciplinary 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 Available	Contact Michael Glantz for more information (see Contacts below).
Computer Requirements	None.
Documentation	Glantz, M., and J. Ausubel. 1998. Impact assessment by analogy: Comparing the impacts of the ogallala aquifer depletion and CO_2 induced climate change. In *Societal Responses to Regional Climate Change: Forecasting by Analogy*. M. Glantz (ed.). Westview Press, Boulder, CO, USA.
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, 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, M. (ed.). 1998. *Societal Responses to Regional Climatic Change: Forecasting by Analogy*. Westview Press, Boulder, CO, USA. Coastal: Hands, E.B. 1983. The Great Lakes as a test model for profile responses to sea level changes. In *CRC Handbook of Coastal Processes and Erosion,* Komar, P.D. (ed.). CRC Press, Boca Raton, pp. 167-189. N. Mimura and H. Nobuoka. 1995. Verification of the Bruun Rule for the estimation of shoreline retreat caused by sea-level rise. In *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 Niño Primer*. FAO Rome. (http://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. NOAA, OGP, Silver Spring, MD, USA.

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 allows 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 Available	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. EPA. draft. Guidelines for Preparing Economic Analyses. U.S. Environmental Protection Agency, Washington, DC.
Applications	Used to help determine total programmatic effectiveness of the Global Environment Facility (GEF).
Contacts for Tools, Documentation, 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: http://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 and variability 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 US$2 million. 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 used 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 are 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 Available	Building Systems Design (see Contacts below) offers monthly training classes.
Computer Requirements	IBM compatible computer with Windows 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 U.S. 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, Technical Assistance	*Tools and Documentation:* Roy Braden, Cost Engineering Branch, Headquarters, U.S. 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.

4. Sector-Specific Tools

The tools described in this section of the compendium are examples of tools that an analyst might consider employing within a given sector and tend to be applicable to only one sector. However, the tools described in each section here should by no means be considered a comprehensive listing of tools that are available. The following sectors are included: agriculture, water, coastal resources, and human health.

4.1 Agricultural Sector Tools

The agricultural sector tools described in this compendium, listed in Table 4.1, 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 single crops (e.g., WOFOST, ICASA, ALFALFA, ORYZA), multiple crops (e.g., APSIM), and entire ecosystems (e.g., CENTURY). Other tools can be used to examine particular ecological factors or processes (e.g., ACRU) or support bigger picture strategic adaptation decisions (e.g., MAACV, RRI). The economic models (e.g., Ricardian analysis and input-output accounting) assist the user in evaluating the economic impacts of changing land values, supply and demand, and commodity production resulting from climate change. There are substantially more agricultural sector tools than there are tools in other sectors. This is because many agricultural models are crop specific or are applicable only to particular regions, whereas models in other sectors tend to be more generally applicable.

Table 4.1. Tools covered in agricultural sector

APSIM (Agricultural Production Systems sIMulator)
WOFOST
ACRU (Agricultural Catchments Research Unit)
Process Soil and Crop Models: CENTURY
ORYZA 2000
Information and Decision Support System for Climate Change Studies in South East South America (IDSS-SESA Climate Change)
Decision Support Systems Linking Agro-Climatic Indices with GCM-Originated Climate Change Scenarios
Model of Agricultural Adaptation to Climatic Variation (MAACV)
Relative Risk Index (RRI)
Government Support in Agriculture for Losses due to Climatic Variability
Process Crop Models: International Consortium for Application of Systems Approaches to Agriculture (ICASA) — International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Family of Models
Process Crop Models: General-Purpose Atmospheric Plant Soil Simulator (GAPS 3.1)
Process Crop Models: Erosion Productivity Impact Calculator (EPIC)
Irrigation Model: CROPWAT
Process Crop Models: Alfalfa 1.4
Process Crop Models: AFRC-Wheat
Process Crop Models: RICEMOD
Process Crop Models: GOSSYM/COMAX
Process Crop Models: GLYCIM
Economic Models: Econometric (Ricardian-Based) Models
Economic Models: Input-Output Modeling (with IMPLAN)

APSIM (Agricultural Production Systems sIMulator)

Description	APSIM is a modeling framework with the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or submodels on a common platform. This functionality uses a "plug-in-pull-out" approach to APSIM design. The user can configure a model by choosing a set of submodels from a suite of crop, soil, and utility modules. Any logical combination of modules can be simply specified by the user "plugging in" required modules and "pulling out" any modules no longer required. Its crop simulation models share the same modules for the simulation of the soil, water, and nitrogen balances. APSIM can simulate more than 20 crops and forests (e.g., alfalfa, eucalyptus, cowpea, pigeonpea, peanuts, cotton, lupin, maize, wheat, barley, sunflower, sugarcane, chickpea, tomato). APSIM outputs can be used for spatial studies by linking with geographic information systems (GIS).
Appropriate Use	The APSIM environment is an effective tool for analyzing whole-farm systems, including crop and pasture sequences and rotations, and for considering strategic and tactical planning. APSIM allows users to improve understanding of the impact of climate, soil types, and management on crop and pasture production. It is a powerful tool for exploring agronomic adaptations such as changes in planting dates, cultivar types, fertilizer/irrigation management, etc.
Scope	Site-specific but can be extrapolated to national and regional levels using GIS.
Key Output	Changes in crop and pasture yields, yield components, soil erosion losses, for different climate change scenarios.
Key Input	Soil properties, daily climate data, cultivar characteristics, and agronomic management.
Ease of Use	For trained agronomists. Requires advanced knowledge of plant growth and soil processes.
Training Required	APSIM training takes approximately one week to acquire minimum skills to conduct simple simulations.
Training Available	Training courses are offered by APSRU (see Contacts below).
Computer Requirements	Windows-based PC.
Documentation	Available at: http://www.apsim.info/apsim/Documentation/.
Applications	Used in Australia, APN projects in Asia, and AIACC activities in South America.
Contacts for Framework, Documentation, Technical Assistance	Christopher Murphy, APSRU, PO Box 102, Toowoomba, QLD, 4350, Australia; Tel: +61.07.4688.1394; e-mail: Christopher.Murphy@dpi.qld.gov.au; Support desk: http://www.apsim.info/apsim/default.asp.
Cost	Not identified.
References	McCown, R.L., G.L. Hammer, J.N.G. Hargreaves, D.P. Holzworth, and D.M. Freebairn. 1996. APSIM: A novel software system for model development, model testing and simulation in agricultural systems research. *Agricultural Systems* 50:255-271.

WOFOST

Description	WOFOST simulates the daily growth of a specific crop, given the selected weather and soil data. Each simulation is conducted for selected specific boundary conditions, which comprise the crop calendar and the soil's water and nutrient status. WOFOST follows the hierarchical distinction between potential and limited production. Light interception and CO_2 assimilation are the growth driving processes, and crop phenological development is the growth controlling process. WOFOST can be used to estimate crop production, indicate yield variability, evaluate effects of climate changes or soil fertility changes, and determine limiting biophysical factors. The following crop models are available: wheat, grain maize, barley, rice, sugar beet, potato, field bean, soybean, oilseed rape, and sunflower.
Appropriate Use	WOFOST considers only ecological factors under the assumption that optimum management practices are applied.
Scope	WOFOST is one-dimensional, mechanistic, and site-specific. Its application to regions relies on the selection of representative points, followed by spatial aggregation or interpolation (e.g., linked to a GIS).
Key Output	Crop yield and variability for different climate change scenarios.
Key Input	Rainfall, temperature, wind speed, global radiation, air humidity, soil moisture content at various suction levels, and data on saturated and unsaturated water flow. Data on site-specific soil and crop management.
Ease of Use	For trained agronomists.
Training Required	No formal training required, but advanced knowledge of plant growth and soil processes is needed.
Training Available	Training and support is available for a fee.
Computer Requirements	Windows-based PC.
Documentation	Hijmans R.J., I.M. Guiking-Lens, and C.A. van Diepen. 1994. WOFOST 6.0: User's Guide for the WOFOST 6.0 Crop Growth Simulation Model. Technical Document 12. ISSN 0928-0944. DLO Winand Staring Centre, Wageningen, The Netherlands.
Applications	WOFOST has been used to study the impact of climate change on crop yield potentials and water use in the Rhine basin. WOFOST has also been incorporated in the European Crop Growth Monitoring System (CGMS) of the MARS project (Monitoring Agriculture with Remote Sensing).
Contacts for Framework, Documentation, Technical Assistance	Kees van Diepen, Department of Land Evaluation Methods, The Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Marijkeweg 11/22 P.O. Box 125, 6700 AC Wageningen, The Netherlands; Tel: +31.317.474230; e-mail: diepen@sc.dlo.nl.
Cost	Not identified.
References	Boogaard, H.L., C.A. van Diepen, R.P. Rötter, J.M.C.A. Cabrera, and H.H. van Laar. 1998. User's Guide for the WOFOST 7.1 Crop Growth Simulation Model and WOFOST Control Center 1.5. DLO-Winand Staring Centre, Wageningen, Technical Document 52. Supit, I., A.A. Hooijer, and C.A. van Diepen (eds.). 1994. System Description of the WOFOST 6.0 Crop Simulation Model Implemented in CGMS. Volume 1: Theory and Algorithms. Catno: CL-NA-15956-EN-C. EUR 15956, Office for Official Publications of the European Communities, Luxembourg.

ACRU (Agricultural Catchments Research Unit)

Description	The ACRU model has its origins in a catchment evapotranspiration based study carried out in Natal in the early 1970s. The agrohydrological component of ACRU first came to the fore during research on an agrohydrological and agroclimatological atlas for Natal. ACRU is a multipurpose model that integrates water budgeting and runoff components of the terrestrial hydrological system with risk analysis, and can be applied in crop yield modeling, design hydrology, reservoir yield simulation and irrigation water demand/supply, regional water resources assessment, planning optimum water resource allocation and utilization, climate change, land use and management impacts, and resolving conflicting demands on water resources. The ACRU model uses daily multilayer soil water budgeting and has been developed essentially into a versatile total evaporation model. It has therefore been structured to be highly sensitive to climate and to land cover/use changes on the soil water and runoff regimes, and its water budget is responsive to supplementary watering by irrigation, to changes in tillage practices, or to the onset and degree of plant stress.
Appropriate Use	ACRU can be used at the catchment or subcatchment level to study the impact of climate change and enhanced CO_2 conditions on crop yield and water balances.
Scope	ACRU can operate as site-specific or as a lumped small catchments model. However, for large catchments or in areas of complex land uses and soils, ACRU can operate as a distributed cell-type model.
Key Output	Crop yield and water balances (including irrigation needs, runoff, etc.) for different climate change scenarios.
Key Input	Weather data: maximum and minimum temperatures, rainfall. Catchment: location, area, configuration, altitude. Other data: land cover, soil properties (texture, depth).
Ease of Use	For trained hydrologists and agronomists.
Training Required	No formal training required, but advanced knowledge of plant and soil processes as well as hydrology is needed.
Training Available	Training and support is available from the School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, South Africa.
Computer Requirements	Windows-based PC.
Documentation	Smithers, J. and R. Schulze. 1995. ACRU: Hydrological Modelling System . User Manual Version 3. Available at: http://www.beeh.unp.ac.za/acru.
Applications	ACRU has been used to assess the potential impact of elevated CO_2 and temperature levels and possible changes in precipitation and potential evaporation on crop and runoff production in southern Africa. The model has also been used to study shifts in maize production regions in southern Africa as a consequence of global climate change. A version of ACR linked to the CERES Maize model was used to simulate possible changes in maize production under different fertilizer scenarios over southern Africa.
Contacts for Framework, Documentation, Technical Assistance	Professor Roland E Schulze. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Private Bag X01, Scottsville 3209, Pietermaritzburg, South Africa; Tel: 033.260.5490; e-mail: schulzeR@nu.ac.za.

ACRU (Agricultural Catchments Research Unit) (cont.)

Cost	Not identified.
References	Schulze, R. 1989. ACRU: Background, Concepts and Theory. Report 35, Agricultural Catchments Research Unit, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, South Africa. Schulze, R.E., G. Kiker, and R.P. Kunz. 1993. Global climate-change and agricultural productivity in Southern Africa. *Global Environmental Change* 3:330-349. Tarboton, K.C. and R.E. Schulze. 1991. The ACRU modeling system for large catchment water resources management. *Int. Assoc. Hydrol. Sci. Publ.* 201:219-232.

Process Soil and Crop Models: CENTURY

Description	CENTURY is a general model of plant-soil nutrient cycling that has been used to simulate carbon and nutrient dynamics for different types of ecosystems, including grasslands, agricultural lands, forests, and savannas. CENTURY is composed of a soil organic matter/decomposition submodel, a water budget model, a grassland/crop submodel, a forest production submodel, and management and events scheduling functions. It computes the flow of carbon, nitrogen, phosphorus, and sulfur through the model's compartments. The organic matter structure for C, N, P, and S are identical; the inorganic components are computed for the specific inorganic compound. The grassland/crop production model simulates plant production for different crops and plant communities (e.g., warm or cool season grasslands, wheat, and corn). The forest model simulates the growth of deciduous or evergreen forests in juvenile and mature phases. To simulate a savanna or shrubland, CENTURY uses both of these submodels with some additional code to simulate nutrient competition and shading effects. [Century is also described under terrestrial vegetation.]
Appropriate Use	To study the impact of climate change on net primary production (crops, pastures, forests) as well as carbon and nutrient dynamics (including carbon sequestration), and to explore adaptive agricultural and natural resource management options (tillage, fertilizer, different species and sequences, etc.).
Scope	Site-specific but has been used at watershed, drainage basin, and regional scales using GIS.
Key Output	Changes in soil carbon and nutrient balances, as well as in crop, pasture and forest production, for different climate change scenarios.
Key Input	Monthly average maximum and minimum air temperature; monthly precipitation; soil texture; plant nitrogen; phosphorus and sulfur content; lignin content of plant material; atmospheric and soil nitrogen inputs; initial soil carbon; nitrogen (phosphorus and sulfur optional).
Ease of Use	For trained agronomists and ecologists. Requires advanced knowledge of soil and plant growth processes.
Training Required	CENTURY basic training requires at least 1-2 weeks to acquire minimum skills to conduct simple simulations.
Training Available	Training is offered at NREL, Colorado State University (see Contacts below).
Computer Requirements	Windows-based PC.
Documentation	Available at http://www.nrel.colostate.edu/projects/century5/ and at the Century 4 homepage http://www.nrel.colostate.edu/projects/century/.
Applications	CENTURY has been used in the Loch Vale Watershed Project, a long-term research program designed to assess the effect of global climate change on the Front Range of the Colorado Rockies. Specifically, CENTURY was used to assess the abiotic and biotic controls on forest distribution and productivity as a basis for assessing potential vegetation change for projected climate scenarios.
Contacts for Framework, Documentation, Technical Assistance	Dr William Parton, NREL at Colorado State University, 1499 Campus Delivery Fort Collins, CO 80523-1499, USA; Tel: 970.491.1987; e-mail: billp@nrel.colostate.edu.

Process Soil and Crop Models: CENTURY (cont.)

Cost	Not identified.
References	Hall, D.O., J.M.O. Scurlock, D.S. Ojima, and W.J. Parton. 2000. Grasslands and the global carbon cycle: Modelling the effects of climate change. In *The Carbon Cycle*. T.M.L. Wigley and D.S. Schimel (eds.). Cambridge University Press, Cambridge, UK, pp. 102-114. Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic levels of grasslands in the Great Plains. *Soil Science Society of America Journal* 51:1173-1179.

ORYZA 2000

Description	ORYZA 2000 is the successor to a series of rice growth models. It is an update and integration of the models ORYZA1 for potential production, ORYZA-W for water-limited production, and ORYZA-N for nitrogen-limited production. The model combines several modules: aboveground crop growth, evapotranspiration, nitrogen dynamics, soil-water balance, and others.
Appropriate Use	To study the impact of climate change rice yields and to explore adaptive management options (fertilizer, cultivar type, irrigation strategy, sowing date, etc.).
Scope	Site-specific, but can be used at regional scales using GIS.
Key Output	Rice yield for different climate change scenarios.
Key Input	Daily climate data (irradiation or sunshine hours, minimum temperature, maximum temperature, early morning vapor pressure, mean wind speed, and precipitation), soil properties, and crop management.
Ease of Use	For trained agronomists. Requires advanced knowledge of plant growth processes.
Training Required	ORYZA 2000 training requires 1-2 weeks to acquire minimum skills to conduct simple simulations.
Training Available	Training is offered online at: http://www.knowledgebank.irri.org/oryza2000/whgdata/whlstt0.htm - 30.
Computer Requirements	Windows-based PC.
Documentation	Available at: http://www.knowledgebank.irri.org/oryza2000/.
Applications	Detailed physiological analysis of field experiments, estimation of crop performance and crop management optimization for a given biophysical environment (climate, soil), including expected climate change, breeding and germplasm evaluation.
Contacts for Framework, Documentation, Technical Assistance	Dr. B.A.M. Bouman, Crop, Soil and Water Sciences Division, International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila, Philippines; e-mail: b.bouman@cgiar.org. H.H. van Laar, Crop and Weed Ecology Group, Wageningen University and Research Centre (WUR), P.O. Box 430, 6700 AK Wageningen, The Netherlands; e-mail: gon.vanlaar@wur.nl.
Cost	Not identified.
References	Bouman, B.A.M., M.J. Kropff, T.P. Tuong, M.C.S. Wopereis, H.F.M. ten Berge, and H.H. Van Laar. 2001. ORYZA2000: Modeling Lowland Rice. International Rice Research Institute, Los Baños, Philippines and Wageningen University and Research Centre, Wageningen, The Netherlands. Matthew, R.B., D. Bachelet, and H.H. van Laar (eds.). 1995. *Modeling the Impact of Climate Change on Rice Production in Asia*. CAB International, Wallingford, United Kingdom.

Information and Decision Support System for Climate Change Studies in South East South America (IDSS-SESA Climate Change)

Description	The IDSS SESA is based on the linking and integration of (a) maps and associated databases of soils, weather, land use, and political divisions; (b) national and regional statistics (production, socioeconomic, demographic); (c) prices of inputs and products; (d) remotely sensed acquired information (crops, pastures, natural resources, climate); (e) simulation models of crop, pasture and forest growth, development and production (DSSAT, APSIM); (f) climate change scenarios (GCMs, RCMs, and statistical methods); (g) a statistical package for analyzing climate data and generating synthetic weather (LARS and MARKSIM); (h) methods for land use evaluation and for defining land use feasibility classes; (i) a simulation model of soil carbon and nutrient dynamics (CENTURY); (j) tools for agricultural applications of global positioning systems (GPS); and (k) geographic information systems (GIS) to process and analyze maps and databases and to generate information that can be easily understandable and applied by agricultural stakeholders. Climate change scenarios are defined using three methods: (1) studying the changes in climate during the last 100 years and projecting those changes for the near future; (2) using sensitivity analyses, i.e., modifying observed weather data with combinations of changes in temperatures max and min and rainfall and generating synthetic weather data; and (3) using GCMs to estimate monthly anomalies of weather (temperatures and rainfall) or atmospheric variables (SLP, geopotential at 850 mb, etc.) and modifying the observed climatic data.
Appropriate Use	To study the impacts of possible climate change scenarios on different agricultural production systems (livestock, crops, mixed) and on the natural resource base, and explore adaptive technological options (crop/pasture management, input use, mixes of crop and pasture types).
Scope	Agro-ecological zone level (national, regional).
Key Output	Changes in agricultural productivity and economic results, variation in agricultural and environmental risks, etc., for different climate change scenarios. Produces outputs (e.g., maps, tables, etc.) in formats easily understood by nonspecialist users such as policy makers and farmers.
Key Input	Soils, weather, and land use data; national and regional statistics of crop/livestock production; prices of inputs and products.
Ease of Use	For trained agronomists.
Training Required	Requires training on the basic tools included in the IDSS: simulation models, GIS, weather generators, and statistical analyses.
Training Available	Training is available for some of the IDSS components (DSSAT, APSIM, CENTURY).
Computer Requirements	Windows-based PC.
Documentation	http://sedac.ciesin.columbia.edu/aiacc/methods.html.
Applications	Used in INIA-Uruguay, INTA-Argentina, IAPAR-Brazil, EMBRAPA-Trigo, Brazil, and the AIACC project LA 27.

Information and Decision Support System for Climate Change Studies in South East South America (IDSS-SESA Climate Change) (cont.)

Contacts for Tools, Documentation, Technical Assistance	Walter E. Baethgen IFDC-Uruguay, Juan M. Perez 2917 Apt. 501, Montevideo, Uruguay; Tel: 598.2.712.0838; e-mail: wbaethgen@undpfim.org.uy. Agustín Giménez, INIA La Estanzuela, Colonia, Uruguay 70000; Tel: 598.574.8000. Graciela Magrin, INTA Castelar, Buenos Aires; Tel: 54.11.4621.1684.
Cost	Not identified.
References	Baethgen, W.E., R. Faría, A. Giménez, and P. Wilkens. 2001. Information and decision support systems for the agricultural sector. In *Proceedings — Third International Symposium on Systems Approaches for Agricultural Development, Lima, Peru, 8-10 November 1999* [CD-ROM computer file]. International Potato Center (CIP), Lima, Peru.

Decision Support Systems Linking Agro-Climatic Indices with GCM-Originated Climate Change Scenarios

Description	Key agro-climatic indices for the crops under study are defined (e.g., crop heat units, growing degree-days, effective growing degree-days, precipitation deficits, seasonal crop coefficients of water demand). Typically these indices are calculated using gridded monthly observed climatic normals for average daily maximum and minimum air temperature, total precipitation, and solar radiation. Climate change scenarios are then obtained from the outputs of GCMs and different statistical packages are used for interpolating and downscaling the results (e.g., PRISM, ANUSPLIN). The agro-climatic indices are then recalculated for the climate change scenarios, and adaptive management options are explored (different crop species, different cultivars, sowing dates, etc.).
Appropriate Use	To study expected shifts in the agro-climatic zones for different crop types under possible climate change scenarios, and to explore the adaptive ability of crop types and management options (planting date, cultivar types).
Scope	Agro-ecological zone level (national, regional).
Key Output	Changes in crop yields, shifts in agro-ecological zones, relative to different climate change scenarios.
Key Input	Gridded observed climate data, agro-climatic indices for different crop species and cultivars.
Ease of Use	For trained agronomists and agro-climatologists.
Training Required	Requires knowledge of agro-climatic indices, and methods for climatic data interpolation and downscaling (e.g., ANUSPLIN, PRISM).
Training Available	See Contacts below.
Computer Requirements	Windows-based PC.
Documentation	PRISM: Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology* 33:140-158. ANUSPLIN: Hutchinson, M.F. 2000. ANUSPLIN Version 4.1 User Guide. Centre for Resource and Environmental Studies, Australian National University, Canberra ACT 0200, Australia.
Applications	Used by Canadian Climate Change Action Projects.
Contacts for Tools, Documentation, Technical Assistance	Contact the Climate Change Impacts & Adaptation Directorate, Natural Resources Canada, e-mail: adaptation@nrcan.gc.ca; or Dr. A. Bootsma, Agriculture and Agri-Food Canada; Tel: 613.759.1526; e-mail: bootsmaa@em.agr.ca. Dr. D. Neilsen, Agriculture and Agri-Food Canada; Tel: 250.494.6417; e-mail: NeilsenD@em.agr.ca.
Cost	Not identified.

Decision Support Systems Linking Agro-Climatic Indices with GCM-Originated Climate Change Scenarios (cont.)

References	Bootsma1, S.G. and D.W. McKenney. 2001. Adaptation of Agricultural Production to Climate Change in Atlantic Canada. Report for Climate Change Action Fund Project A214. http://adaptation.nrcan.gc.ca/app/filerepository/7B21EDC8493044E8989F4B199AF6E658.pdf. Neilsen, D., S. Smith, W. Koch, G. Frank, J. Hall, and P. Parchomchuk. 2001. Impact of Climate Change on Crop Water Demand and Crop Suitability in the Okanagan Valley, BC. Technical Bulletin 01-15. Pacific Agri-Food Research Centre, Summerland, British Columbia, Canada. http://adaptation.nrcan.gc.ca/app/filerepository/79CAB598141A4FEE9AF5492AA38FCE7F.pdf

Model of Agricultural Adaptation to Climatic Variation (MAACV)

Description	Computer and numerical models require assessment of system forces and responses to adaptation in order to understand the context for the variables being considered. This model illustrates the endogenous and exogenous forces that influence adaptation responses and classifies those responses into various farm and regional level responses. The biophysical environment, government programs, economic conditions, and other forces are the exogenous considerations and factors such as the attributes of the farmer, the farm family, and the farm, including their experiences, perceptions, location, scale, and finances, are the endogenous considerations made in this model. Farm responses include tactical and strategic decisions.
Appropriate Use	Provides structure and hypotheses for numerical impact assessments in agriculture; particularly for developed economies.
Scope	All locations; farm and regional level analyses of commercial farming systems.
Key Output	Classification of range of forces and responses to adaptation to climatic variation.
Key Input	System and human agency influences on adaptation responses.
Ease of Use	Easy.
Training Required	No formal training required, although an understanding of farming systems is an asset.
Documentation	Smit, B., D. McNabb, and J. Smithers. 1996. Agricultural adaptation to climatic variation. *Climatic Change* 33:7-29.
Applications	Applied in research of corn hybrid adaptation in Ontario, Canada, and in the University of Guelph's Farming Systems Research.
Contacts for Tools, Documentation, Technical Assistance	Dr. Barry Smit and Dr. John Smithers, University of Guelph, Department of Geography, Guelph, ON N1G 2W1 Canada; Tel: (519) 824-4120 ext. 3279; Fax: (519) 837-2940; e-mail: bsmit@uoguelph.ca. D. McNabb, Carleton University, Impact Assessment Centre, Ottawa, ON K1S 5B6 Canada; Tel: 613.520.2547; Fax: 613.520.2551.
Cost	Not identified.
References	Smit, B. 1999. Agricultural Adaptation to Climate Change in Canada. A Report to the Adaptation Liaison Office. Smit, B., D. McNabb, and J. Smithers. 1996. Agricultural adaptation to climatic variation. *Climatic Change* 33:7-29.

Relative Risk Index (RRI)

Description	RRI illustrates the overall level of risk a farmer faces in light of various cropping decisions and climatic variation. In the study referenced here, various levels of risk are categorized and rated and then the proportion of the total farm area planted to each category of risk is calculated. The index is determined on the basis of the proportion of relatively risky versus relatively conservative crops planted.
Appropriate Use	To illustrate the relative risk positions of individuals (before or after adaptation) and begin to explain changes in cropping practices.
Scope	All locations; farm or regional level analyses.
Key Output	A relative risk index.
Key Input	Data on annual variations in cropping practices.
Ease of Use	Easy.
Training Required	No formal training required, although an understanding of various agronomic practices is an asset.
Documentation	Smit, B., R. Blain, and P. Keddie. 1997. Corn hybrid selection and climatic variability: Gambling with nature? *The Canadian Geographer* 41(4):429-438.
Applications	Used in research of commercial cash crop farming in Ontario, Canada.
Contacts for Tools, Documentation, Technical Assistance	Dr. Barry Smit, University of Guelph, Department of Geography, Guelph, ON N1G 2W1 Canada; Tel: 519.824.4120 ext. 3279; Fax: 519.837.2940; e-mail: bsmit@uoguelph.ca.
Cost	Not identified.
References	See Documentation above.

Government Support in Agriculture for Losses due to Climatic Variability

Description	A methodology using descriptive statistics to summarize data on government supports for extreme weather and climate variability in agriculture. Government sponsored programs such as Crop Insurance and Ad hoc Disaster Payment programs are considered in terms of their changing value over time.
Appropriate Use	To describe and evaluate the sustainability of government support programs that are provided in response to climate variability and weather extremes.
Scope	All locations; provincial and national level analyses.
Key Output	Value of government programs providing payments to farmers directly related to climatic variability.
Key Input	Farm income and government support data.
Ease of Use	Easy.
Training Required	No formal training required, although an understanding of government support programs, farming systems and descriptive statistics is an asset.
Computer Requirements	Spreadsheet software package.
Documentation	See Smit, B., 1994, in References below.
Applications	Used by the Environmental Adaptation Research Group of Environment Canada, Ontario Ministry of Agriculture, Food and Rural Affairs and Canada's National Implementation Strategy.
Contacts for Tools, Documentation, Technical Assistance	Dr. Barry Smit, University of Guelph, Department of Geography, Guelph, ON N1G 2W1 Canada; Tel: 519.824.4120 ext. 3279; Fax: 519.837.2940; e-mail: bsmit@uoguelph.ca.
Cost	Not identified.
References	Smit, B. 1999. Agricultural Adaptation to Climate Change in Canada. A Report to the Adaptation Liaison Office. Smit, B. 1994. Climate, compensation and agriculture. In *Improving Responses to Atmospheric Extremes: The Role of Insurance and Compensation. Workshop Proceedings.* J. McCulloch and D. Etkin (eds.).The Climate Institute, Environment Canada, Toronto.

Process Crop Models: International Consortium for Application of Systems Approaches to Agriculture (ICASA) — International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Family of 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	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 Available	Fee-based training courses are offered regularly by IBSNAT (see Contacts 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 25MB 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.
Applications	Used by numerous countries in the U.S. Country Studies Program, including Egypt, Kazakhstan, and Uruguay.
Contacts for Tools, Documentation, 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 *Wheat Growth and Modeling*. W. Day and R.K. Atkin (eds.). Plenum Publishing, New York, 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	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 Available	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. Dept. of Agronomy, Cornell University, Ithaca, NY. Can be downloaded from: http://environment.eas.cornell.edu/riha.html
Applications	Used to examine farm-level impacts of climate change on agriculture in the midwestern U.S.
Contacts for Tools, Documentation, 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, modifying 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 Available	Informal training available; see below.
Computer Requirements	IBM-compatible PC 486 with 4k of RAM and 80MB.
Documentation	Williams, J.R., C.A. Jones, and P.T. Dyke. 1990. The EPIC model documentation. USDA-ARS Technical Bulletin No. 1768. U.S. Department of Agriculture, Washington, DC. 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, 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.

Process Crop Models: Erosion Productivity Impact Calculator (EPIC) (cont.)

References	Williams, J.R., C.A. Jones, and P.T. Dyke. 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, and J.R. Williams. 1992. Preparing the erosion productivity impact calculator (EPIC) model to simulate crop response to climate change and the direct effects of CO_2. *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	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 the 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 Available	No formal training currently offered beyond the training manual.
Computer Requirements	IBM-compatible PC 486 with 4k of RAM and 80MB 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 six 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, 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. Food and Agriculture Organization, Rome.

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	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	Daily weather data from standard meteorological reports.
Ease of Use	Relatively easy to use with sufficient background.
Training Required	Advanced programming skills (knowledge of FORTRAN language) helpful, agronomic background required.
Training Available	No formal training currently offered beyond the training manual.
Computer Requirements	DOS, Windows, or Macintosh environments. Instructions for downloading given at the website below in Contacts.
Documentation	Denison, R.F. and B. Loomis. 1989. An Integrative Physiological Model of Alfalfa Growth and Development. UC ANR Publication 1926, University of California, Davis.
Applications	Used by farmers in the U.S.
Contacts for Tools, Documentation, Technical Assistance	R. Ford Denison, Agronomy and Range Science, University of California, Davis, 95616, USA; Tel: +1.530.752.9688; e-mail: rfdenison@ucdavis.edu.
Cost	Program and manual available for US$25.
References	Denison, F. and B. Loomis. 1989. An Integrative Physiological Model of Alfalfa Growth and Development. UC ANR Publication 1926. University of California, Davis.

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 maximum, minimum, 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 Available	See web site in Contacts 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, in 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, 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* 102:371-383. Addiscott, T.M., P.J. Heys, and A.P. Whitmore. 1986. Application of simple leaching models in heterogeneous 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* 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	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. Does not include the influence of CO_2.
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, CO_2 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 Available	IRRI (see Contacts 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. 1099 Manila, The Philippines.
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, 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; websites: http://www.cgiar.org/ and http://www.irri.org/
Cost	Contact IRRI for information.
References	See Documentation above.

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.
Appropriate Use	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; 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 (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 Available	Short training course offered (see Contacts below).
Computer Requirements	An IBM-compatible 486 with 4K of RAM and 80MB.
Documentation	Application manual available (see Cost 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, 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, and 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 groundwater quality. Amendable to the testing of management adjustments to climate variation.
Scope	All locations; agricultural sector; site-specific.
Key Output	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 Available	Mississippi State University can provide training.
Computer Requirements	Requires an IBM-compatible 486, with 4K 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, 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 downloaded free from website (see Documentation above).
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 Available	No formal training offered.
Computer Requirements	IBM-compatible PC.
Documentation	See Mendelsohn et al., 1994, in References below.
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, 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 University Press, Cambridge, England. Dinar, A., R. Mendelsohn, R. Evenson, J. Parikh, A. Sanghi, K. Kumar, J. McKinsey, and S. Lonergon. 1998. Measuring the Impact of Climatic Change on Indian Agriculture. World Bank Technical Report No. 409, The World Bank, Washington, DC.

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 US$1.00 change in final demand for any given industry.
Appropriate Use	Serves three functions: data retrieval, data reduction and model development, and 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 provide a high degree of flexibility in terms of both 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. Designed specifically for the U.S., but basic model structure can be adapted and applied to other countries where data are available.
Scope	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 Available	MIG Workshops (see Contacts below) provides training for the use of IMPLAN in economic analysis. Workshops are held either in MIG's Minnesota USA 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 in Contacts 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.

Economic Models: Input-Output Modeling (with IMPLAN) (cont.)

Contacts for Tools, Documentation, 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: http://www.implan.com/. Technical Assistance: http://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. *Climatic Change* 24:131-158.

4.2 Water Sector Tools

The water sector tools described in this compendium, listed in Table 4.2, 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. RIBASIM allows for the assessment of infrastructure, and operational and demand management measures. MIKEBASIN provides basin scale solutions for optimizing water allocations, conjunctive water use, reservoir operation, and water quality issues, emphasizing results visualization through a GIS interface.

Table 4.2. Tools covered in water sector

WaterWare
Water Evaluation and Planning System (WEAP)
RiverWare
Interactive River and Aquifer Simulation (IRAS)
Aquarius
RIBASIM
MIKE BASIN
(STREAM)

WaterWare

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. WaterWare is implemented in an open, object-oriented architecture; it supports the seamless integration of databases, GIS, models, and analytical tools into a common sense, easy-to-use framework. This includes a multimedia user interface with Internet access, a hybrid GIS with hierarchical map layers, object data bases, time series analysis, reporting functions, an embedded expert system, and a hypermedia help-and-explain system. Real-time data management, modeling, forecasting, and reporting, and support for operational management are provided with a real-time expert system. 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. Geographic: background maps with administrative boundaries, landuse; river network (geometry) graph and segment geometry (cross sections, roughness) for all channel based models. River Basin Objects: these include classes such as subcatchments, aquifers, lakes and reservoirs, cities, industries, agricultural areas and irrigation districts, representing the nodes in the river network; for each object, and depending on the type of object, data on water demand, use, consumptive use, and wastewater generation (pollution loads) are required. For aquifers, basic hydrogeological data are required; for reservoirs, morphometry and operating rules. Hydrological and Meteorological: Time series of basic hydrometeorological data (hourly to daily) covering at least one year or the period of interest for the long-term models), temperature and precipitation, optionally relative humidity, wind speeds,. cloud cover and solar radiation, potential evapotranspiration. Water Quality: hourly to daily observation data from one or more water quality observation stations; station location and regular time series for each parameter. 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.

WaterWare (cont.)

Training Required	Significant training in computer modeling and the engineering, environmental, and economic aspects of water systems.
Training Available	Software purchase includes on-site installation. Training courses and on-site training available (see Contacts 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 (see Contacts below).
Applications	River Thames in England, Lerma Chapala in Mexico, West Bank and Gaza in Palestine, Kelantan River in Malaysia. River basins and coastal zones in Turkey, Lebanon, Jordan, Egypt, and Tunisia.
Contacts for Framework, Documentation, 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, P.O. Box 100 A-2352 Gumpoldskirchen, Austria.

Water Evaluation and Planning System (WEAP)

Description	This is a PC 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; changes in instream flow requirements; implications of new infrastructure development. Strengths include detailed demand modeling.
Scope	All locations, surface- and groundwater systems; national, international 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 (can use GIS layers for background) and component capacities and operating policies. 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, socioeconomic projections, water supply projections.
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 Available	On-line tutorial available at http://www.weap21.org/. Contact SEI for details regarding available training (see below).
Computer Requirements	200 MHz or faster Pentium class PC with Microsoft Windows 95 or later (a 400 MHz PC with Windows 98 or later is recommended). A minimum of 32 MB of RAM and 50 MB of free hard disk space is also required (64 MB of RAM recommended). In addition Microsoft Internet Explorer version 4.0 is required for viewing WEAP's HTML Help. Monitor should be set to a minimum resolution of 800x600, but preferably even higher (e.g., 1024x768 or 1280x1024), to maximize the presentation of data and results.
Documentation	WEAP21 User Guide; available online at http://www.weap21.org as pdf file/.
Applications	Has been used for projects in the Aral Sea; Beijing, China; Rio San Juan, Mexico; Rajasthan, India; South Africa; West Africa; California, Texas, and Southeast, USA; Central Asia; India; Nepal; Korea; and Cairo, Egypt.
Contacts for Framework, Documentation, Technical Assistance	Jack Sieber, Senior Software Scientist, 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.weap21.org/.

Water Evaluation and Planning System (WEAP) (cont.)

Cost	US$2000 for commercial users includes free upgrades and technical support; discounts available for government, universities, and not-for-profit organizations; free to developing countries.
References	Huber-Lee, A., D. Yates, D. Purkey, W. Yu, and B. Runkle. 2003. Water, climate, food, and environment in the Sacramento Basin — contribution to ADAPT: Adaptation strategies to changing environment. Stockholm Environment Institute, Boston, MA, USA. 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. Hansen, E. 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, p. 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 non-spatial (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 Available	CADSWES regularly holds training workshops in Boulder, CO, USA (see Contacts below).
Computer Requirements	Sun Solaris (Unix) workstation with Solaris 2.7 or higher operating system, or Windows NT/2000/XP; system memory requirements depend on river/reservoir model size and data; a minimum of 256MB is recommended. CPLEX, a third-party solver, is required to run the RiverWare Optimization module.
Documentation	Detailed documentation available through CADSWES; RiverWare description at http://cadswes.colorado.edu/riverware/.
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). The model has also been applied in the San Juan Basin and Upper Rio Grande.

RiverWare (cont.)

Contacts for Framework, Documentation, Technical Assistance	Center for Advanced Decision Support in Water and Environmental Systems (CADSWES), University of Colorado, Campus Box 428, Boulder, CO 80309-0428 USA; e-mail: rwinfo@cadswes.colorado.edu; website: http://cadswes.colorado.edu/riverware/.
Cost	Licensed Single node license US$6500 for first year; US$2500 annual renewal fee; additional fees for optimization solver.
References	Zagona, E.A., T.J. Fulp, R. Shane, T. Magee, and H.M. Goranflo. 2001. RiverWare: A generalized tool for complex reservoir systems modeling. *Journal of the American Water Resources Association* 37(4):913-929.

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; 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 Available	Contact RPA for details regarding available training (see Contacts below).
Computer Requirements	IBM-compatible PC with Windows 95 or higher. 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 Framework, Documentation, 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: http://www.cfe.cornell.edu/research/urbanwater/project%20description/General/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. CH2M Hill, Parsippany, NJ, USA. 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, USA.

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. Supports the following water uses (system components) storage reservoir, hydropower plants, agricultural water use, municipal and industrial water use, instream recreation water use, reservoir recreation use, and instream flow protection. For a water use with a predetermined level of allocation but without a defined economic demand function, the analyst can either constrain the model to meet the specified allocation or experiment with surrogate demand curves until the required level of water allocation is reached. The latter approach indicates the level of economic subsidy required to provide the incremental increases of flow to sustain the use in open competition with other uses. The interactive nature of Aquarius facilitates such experimentation.
Scope	All locations; surface and groundwater systems; cost-effectiveness; national or site-specific.
Key Output	Economically efficient allocations that meet prescribed demands.
Key Input	The model's input data have been divided into physical and economic data. The physical data include the information associated with the dimensions and operational characteristics of the system components, such as maximum reservoir capacity, percent of return flow from an offstream demand area, and powerplant efficiency. The economic data consist mainly of the 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 Available	Questions regarding software availability and training can be directed to Gustavo E. Diaz (see below).
Computer Requirements	PC Windows 95, 98, NT, or Windows 2000 operating system.
Documentation	Model documentation is available on line at http://www.fs.fed.us/rm/value/docs/aquadoc01.pdf.
Applications	Authors not aware of existing applications in developing countries.
Contacts for Framework, Documentation, Technical Assistance	Gustavo E. Diaz, Department of Civil Engineering, Colorado State University, Fort Collins, CO, 80523, USA; Tel: +1.970.491.5048; Fax: +1.970.491.7721; e-mail: gdiaz@lamar.colostate.edu; website: http://www.fs.fed.us/rm/value/aquariusdwnld.html.

Aquarius (cont.)

Cost	Model documentation and software is free for government agencies and for teaching and research purposes.
References	Diaz, G.E., T.C. Brown, and O. Sveinsson. 2000. *Aquarius: A Modeling System for River Basin Water Allocation.* General Technical Report RM-GTR-299-revised. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

RIBASIM

Description	RIBASIM is a generic model package for simulating the behavior of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool that links the hydrological water inputs at various locations with the specific water users in the basin. RIBASIM enables the user to evaluate a variety of measures related to infrastructure and operational and demand management, and to see the results in terms of water quantity and flow composition. RIBASIM can also generate flow patterns that provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. Demands for irrigation, public water supply, hydropower, aquaculture, and reservoir operation can be taken into account. Surface- and groundwater resources can be allocated. Minimum flow requirements and flow composition can be assessed.
Appropriate Use	Evaluation of the options and potential for development of water resources in a river basin. Assessment of infrastructure, and operational and demand management measures.
Scope	All locations, surface- and groundwater systems; national or site-specific.
Key Output	Water balance providing the basic information on the available quantity of water as well as the composition of the flow at every location and any time in the river basin. This takes into account drainage from agriculture, discharges from industry and the downstream re-use of water in the basin.
Key Input	Configuration of system (can use GIS layers for background) and component capacities and operating policies. 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, socioeconomic projections, water supply projections.
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 Available	Contact Delft Hydraulics for details regarding available training (see Contacts below).
Computer Requirements	200 MHz Pentium processor; 64 Mb RAM; 400 Mb free disk space; Super VGA graphics card with matching monitor; floppy disc drive; mouse; CD-ROM drive; RIBASIM requires MICROSOFT WINDOWS 95, 98, 2000, or NT.
Documentation	Documentation available from Delft Hydraulics (see Contacts below).
Applications	RIBASIM has been applied for more than 20 years in a wide variety of projects and countries. Water management organizations worldwide use it to support their management and planning activities; Contact Delft Hydraulics for more details.
Contacts for Framework, Documentation, Technical Assistance	WL Delft Hydraulics Rotterdamseweg 185, P.O. Box 177, 2600 MH Delft, The Netherlands. Tel: +31.0.15.285.8585; Fax: +31.0.15.285.8582; e-mail: ribasim.info@wldelft.nl; website: http://www.wldelft.nl/soft/ribasim/int/index.html.
Cost	Relatively low cost to obtain model and documentation.
References	Contact Delft Hydraulics for references.

MIKE BASIN

Description	For addressing water allocation, conjunctive use, reservoir operation, or water quality issues, MIKE BASIN couples the power of ArcView GIS with comprehensive hydrologic modeling to provide basin-scale solutions. The MIKE BASIN philosophy is to keep modeling simple and intuitive, yet provide in-depth insight for planning and management. In MIKE BASIN, the emphasis is on powerful simulation result visualization in both space and time, making it the perfect tool for building understanding and consensus. For hydrologic simulations, MIKE BASIN builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. The ArcView GIS interface has been expanded accordingly, e.g., such that the network elements can be edited by simple right-clicking. Technically, MIKE BASIN is a quasi-steady-state mass balance model, however, allowing for routed river flows. The water quality solution assumes purely advective transport; decay during transport can be modeled. The groundwater description uses the linear reservoir equation.
Appropriate Use	Water availability analysis: conjunctive surface and groundwater use, optimization thereof. Infrastructure planning: irrigation potential, reservoir performance, water supply capacity, waste water treatment requirements. Analysis of multisectoral demands: domestic, industry, agriculture, hydropower, navigation, recreation, ecological, finding equitable trade-offs. Ecosystem studies**:** water quality, minimum discharge requirements, sustainable yield, effects of global change. Regulation: water rights, priorities, water quality compliance.
Scope	All locations; surface- and groundwater 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	Overall system: Digitized river system layout, withdrawal and reservoir locations. Water demand: Time series of water demand, percentage of ground abstraction, return flow ratio, linear routing coefficient (irrigation only). Water supply: Unit naturalized runoff (time series), initial groundwater elevation, linear reservoir time constant, groundwater recharge time series. Hydropower: time series of withdrawal for hydropower, installed effect, tail water level, machine efficiency. Reservoir: Initial water level, operational rule curves, stage-area-volume curve, time series of rainfall and evaporation, linkages to users, priority of delivery, linkages to upstream nodes. Water quality: rate parameters, temperature, non-point loads, weir constant for re-aeration, transport time and water depth or Q-h relationship, concentrations in effluent.
Ease of Use	Relatively easy to use if user is familiar with ArcView software. Requires significant data for detailed analysis.
Training Required	Moderate training/experience in resource modeling required for effective use. Also requires working knowledge of ESRI's ArcView software.
Training Available	MIKE BASIN courses are arranged both regularly and upon request (see http://www.dhisoftware.com/mikebasin/Courses/).
Computer Requirements	ArcView 3.2 or 3.2a; Windows 98, NT, 2000, or XP operating system (MIKE BASIN may also run on Windows 95 and ME, but those operating systems are not officially supported by DHI); minimum 64 MB RAM (recommended); high resolution monitor, minimum 800x600 pixels; minimum 200 MB free disk space.

MIKE BASIN (cont.)

Documentation	Detailed documentation including on-line tours of the model available through their website: http://www.dhisoftware.com/mikebasin/Download/.
Applications	Has been used in Peru; Sabah, Malaysia; Gold Coast, Australia; Idaho and North Carolina, USA; Italy; Poland; Thailand; Sri Lanka; Senegal; Czech Republic; Zambia; and Tanzania.
Contacts for Framework, Documentation, Technical Assistance	DHI's Software Support Centre; Tel: +45.45.16.93.33 Fax: +45.45.16.92.92; e-mail: software@dhi.dk; website: http://www.dhisoftware.com/mikebasin/.
Cost	Licensed software cost US$3000 per class set, US$300 to update each set.
References	Contact DHI for references.

SPATIAL TOOLS FOR RIVER BASIN ENVIRONMENTAL ANALYSIS AND MANAGEMENT (STREAM)

Description	STREAM is a spatial hydrological model that allows for assessing hydrological impacts due to changes in climate and socio economic drivers. STREAM is set up according to a policy analytic framework and ensures a structured approach for an entire river basin including the coastal zone. STREAM uses hydrological input data, scenarios, adaptive strategies and provides output data on water availability and (salt water) quality. It integrates within this frame several types of interactions between effects of river management on the coastal zone, land and water uses such as short term deforestation and dam building, and long term impacts of climate change. STREAM is a spatial model and uses data from digital GIS maps and satellite observations, in particular land-use related data. The basis of the instrument is a grid or raster-based water balance approach. Water use and withdrawals can be simulated such as the spatial distribution of agriculture and urbanization use and the storage of water in the open flood plain and groundwater aquifers. The main advantage of STREAM is that it primarily uses public domain data from the internet providing a very first order of estimates on impacts. This makes the STREAM instrument very flexible for future extensions and adjustments. The next stage of development, calibration and validation, is usually performed in close cooperation with local stakeholders, using local time series of in and output data increasing the level of reliability.
Appropriate Use	The STREAM can be applied to entire river basins with different sizes for which it considers the full year hydrological cycle. For example, in large river basins, a grid size of 1 x 1 km2 can be applied while in the lower regions 100 x 100 m2 grid size is applicable. Time steps can vary from 1 month as an overall step to either decades or 5-day steps for specific periods of interest during the hydrological cycle, such as the flood season.
Scope	STREAM has been primarily applied to studies to assess impacts of climate change, climate variability and land use changes (including dams and reservoirs) to water resources in river basins. For these issues, STREAM enables to calculate the impacts of changes in temperature and precipitation on the regional hydrology. Based on these impacts, different management strategies can be assessed by providing a quantitative assessment of water availability under various scenarios.
Key Output	Key output is a spatial hydrological information on water availability in the form of (monthly) soil-humidity and river discharges. The latter outputs can be both in a hydrograph or in spatial GIS based map.
Key Input	The required input data is: temperature, precipitation, soil types, elevation. And for calibration and validation: Runoff data.
Ease of use	The model is easy to use for non technical users. However, it is best used within a team of both hydrological experts and policy makers. Some GIS knowledge is required.
Training Required	Some GIS knowledge and training is required to prepare the input data of the model. Also some basic hydrological knowledge is an advantage but is nor necessary.

SPATIAL TOOLS FOR RIVER BASIN ENVIRONMENTAL ANALYSIS AND MANAGEMENT (STREAM)(Cont.)

Training Offered	A setup manual is delivered with the model. It however recommended to follow a short introductory course by the distributor and RIKZ.
Computer Requirements	The minimum hardware requirement is a PIII – 500MhZ computer with 256 MB internal memory
Documentation	Aerts, J.C.J.H. and Bouwer, L. 2003. STREAM Manual version 2.0. IVM internal report.
Applications	STREAM has been applied to the following river basins: Rhine (Europe), Meuse (Europe), Amu Darya (Central Asia), Syr Darya (Central Asia), Nile (Africa), Niger (Africa), Incomati (Africa), Zambezi (Africa), Ganges/Brahmaputra (Asia), Yangtze (China), Krishna (India), Perfume (Vietnam).
Contacts for Framework, Documentation and Technical Assistance	Publications available at website: http://www.geo.vu.nl/users/ivmstream/ Drs. Robbert Misdorp, Coastal Zone Management Centre/National Institute for Coastal and Marine Management (RIKZ),Ministry of Transport, Public Works and Water Management Kortenaerkade 1, PO BOX 20907, 2500EX The Hague. The Netherlands; Tel: +31-70-3114311, Fax: +31-70-3114300, e-mail: R.Misdorp@chello.nl, http://www.netcoast.nl Dr. Jeroen Aerts, Senior Researcher Water Resources, Climate Change Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands, Tel. + 31 (0) 20 4449528 / 9555, fax. + 31 (0) 20 4449553, e-mail: jeroen.aerts@ivm.vu.nl http://www.falw.vu.nl/home/index.cfm
Cost	A STREAM-DEMO tool can be acquired for free. After registering a free copy of the Model can be obtained through the IVM – STREAM Website. The development of a first order Internet-based STREAM for a new river basin can be accomplished within a month.
References	Aerts J.C.J.H., M. Kriek and M. Schepel 1999. STREAM, spatial tools for river basins and environment and analysis of management options: ‘Set up and requirements’. *Physics and Chemistry of the Earth Part B*, 24(6), 591-595. Aerts, J.C.J.H., A. Hassan, H.H.G. Savenije and M.F. Khan 2000. Using GIS tools and rapid assessment techniques for determining salt intrusion: STREAM, a river basin management instrument. *Physics and Chemistry of the Earth Part B*, 25(3), 265-273.

4.3 Coastal Resources Tools

Coastal areas have been a particular focus for consideration of adaptation to sea level rise and climate change, as well as the relationship of adaptation to wider coastal management. The coastal tools described in this compendium (and listed in Table 4.3) are part of these efforts. They can assist the user in evaluating different coastal management strategies.

These tools include decision-support and qualitative to semiquantitative methods focused on climate change such as the UNEP Handbook Methodology, SPIM, historical and geographic analogs (described in Section 3.4 of this compendium), and the IPCC Common Methodology, which are useful as initial analyses for applications where limited quantitative data are available. These dominantly bottom-up methods are particularly relevant in developing countries where quantitative data are limited but local expertise is abundant. The most quantitative method is the DIVA tool, which comprises a quantitative national, regional, and global vulnerability method supported by data, algorithms, and a graphical user interface. It should allow scoping studies of any coastal area, before focusing on more detailed studies.

The other types of coastal sector tools considered here are more quantitative and specific tools focused more broadly on coastal management, including the physical and economic impacts of climate change under a range of management options. The Coastal Zone Management Centre in the Netherlands (http://www.netcoast.nl/tools/tools.htm) describes a range of such tools. These tools, which attempt to integrate the complex range of factors associated with coastal zone management, include processes that are still the subject of fundamental research. Therefore, they remain primarily educational and research tools rather than planning and evaluation methods. They provide interesting evaluations and are continually being improved. They can also be used in conjunction with more accessible methods such as UNEP and IPCC. The models COSMO, RamCo, and ISLAND MODEL are described here. Lastly, Shoreline Management Planning (SMP) is a generic approach to selecting strategic approaches to manage flood and erosion hazards in the coastal zone over the long-term. This type of approach has been applied in developed countries, but is applicable in many developing countries.

Table 4.3. Tools covered in coastal sector

IPCC Common Methodology
UNEP Handbook Methodology
Decision Support Models: COSMO (COastal zone Simulation MOdel)
The South Pacific Island Methodology (SPIM)
RamCo and ISLAND MODEL
Dynamic Interactive Vulnerability Assessment (DIVA)
Shoreline Management Planning (SMP)

IPCC Common Methodology

Description	Influential framework first proposed in 1991 that 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. Adaptation focuses around three generic options: retreat, accommodate or protect.
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; and scale; subnational, national, 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 and associated value and uses, wetland loss, etc.
Key Input	Physical and socioeconomic characteristics of the study area.
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 seven steps (weeks or months); often performed by external consultants rather than in-country experts.
Training Available	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	Original documentation from 1991 is unavailable. Update provided in Appendix C in 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.

IPCC Common Methodology (cont.)

Applications	Used in many coastal countries, including within the Dutch Country studies program, and in an adapted form in the U.S. CSP (e.g., Egypt, Germany, Poland, Netherlands, Guyana, Vietnam, Bangladesh; Suriname) (e.g., see http://www.netcoast.nl/tools/tools.htm). Examples of studies: O'Callahan, J. (ed.), 1994: *Global Climate Change and the Rising Challenge of the Sea*. Proceedings of the third IPCC CZMS workshop, Isla de Margarita, Venezuela, 9–13 March 1992, National Oceanic and Atmospheric Administration, Silver Spring, MD, v+691 pp. Hoozemans, F.M.J., M. Marchand, and H.A. Pennekamp. 1993. *Sea Level Rise: A Global Vulnerability Assessment — Vulnerability Assessments for Population, Coastal Wetlands and Rice Production on a Global Scale.* Second revised edition, Delft Hydraulics and Rijkswaterstaat, Delft and The Hague, The Netherlands, xxiii+184 pp. Nicholls, R.J. and S.P. Leatherman (eds.). 1995. The potential impacts of accelerated sea-level rise on developing countries. *Journal of Coastal Research*, Special Issue No 14, 323 pp. Mimura, N. and H. Harasawa (eds.). 2000. *Data Book of Sea-Level Rise*. Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan. De La Vega-Leinert, A.C., R.J. Nicholls, and R.S.J. Tol. (eds.). 2000. European Vulnerability & Adaptation to impacts of Accelerated Sea-Level Rise (ASLR). Second workshop, Hamburg, Germany — 19-21 June, Flood Hazard Research Centre, Middlesex University, UK (downloadable at www.survas.mdx.ac.uk). De La Vega-Leinert, A.C. and R.J. Nicholls (eds.). 2001. Proceedings of the Survas Overview Workshop on the Future of Vulnerability and Adaptation Studies. The Royal Chace, London, 28-30 June, Flood Hazard Research Centre, Middlesex University, London (downloadable at www.survas.mdx.ac.uk).
Contacts for Tools, Documentation, 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., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H. Perez Nieto, E.Z. Stakhiv, R.K. Turner, and R.A. Warrick. 1996. Coastal zones and small islands. In *Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, The Second Assessment Report of the Intergovernmental Panel on Climate Change, Working Group II*, R.T. Watson, M.C. Zinyowera, and R.H. Moss (eds). Cambridge University Press, Cambridge, UK pp. 289-324. Nicholls, R.J. and N. Mimura. 1998. Regional issues raised by sea-level rise and their policy implications. *Climate Research* 11:5-18. Nicholls, R.J. 1998. Assessing erosion of sandy beaches due to sea-level rise. In *Geohazards in Engineering Geology*, J.G. Maund and M. Eddleston (eds.). Geological Society, London. Engineering Special Publication, 15:71-76. Klein, R.J.T. and R.J. Nicholls. 1999. Assessment of coastal vulnerability to climate change. *Ambio* 28(2):182-187.

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 seven 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. The possibility of a quick screening assessment followed by a more detailed vulnerability assessment has been suggested (Klein and Nicholls, 1999). Information gathered with this methodology can then be used as input for future modeling.
Scope	Coastal; and scale; sub-national, national, regional and global analysis.
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 or quantitative 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 and the level of analysis that is attempted, but it is likely that some training is required to complete the seven steps.
Training Available	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 *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies* (Version 2.0). J. Feenstra, I. Burton, J. Smith, and R. Tol (eds.). United Nations Environment Programme, Nairobi, and Institute for Environmental Studies, Vrije Universiteit, Amsterdam. (Version 2.0). http://www.falw.vu.nl/images_upload/151E6515-C473-459C-85C59441A0F3FB49.pdf.
Applications	Used in several countries, including the Cameroon, Antigua and Barbuda, Estonia, Pakistan, Cuba, Grenada, Guyana and Barbados.
Contacts for Tools, Documentation, Technical Assistance	Dr. Michiel van Drunen, Institute for Environmental Studies, Vrije Universiteit, Amsterdam; Tel: +31-20-5989534; e-mail: michiel.van.drunen@ivm.falw.vu.nl.
Cost	No cost to obtain documentation.

UNEP Handbook Methodology (cont.)

References	Nicholls, R.J. 1998. Coastal Vulnerability Assessment for Sea-Level Rise: Evaluation and Selection of Methodologies for Implementation. Technical Report TR098002, Caribbean Planning for Adaptation to Global Climate Change (CPACC) Project (downloadable from www.cpacc.org). Klein, R.J.T. and R.J. Nicholls. 1999. Assessment of coastal vulnerability to climate change. *Ambio*, 28(2):182-187. Klein, R.J.T., R.J. Nicholls, and N. Mimura. 1999. Coastal adaptation to climate change: Can the IPCC Technical Guidelines be applied? *Mitigation and Adaptation Strategies for Global Change*, 4:51-64. Klein, R.J.T., R.J. Nicholls, S. Ragoonaden, M. Capobianco, J. Aston, and E.N. Buckley. 2001. Technological options for adaptation to climate change in coastal zones. *Journal of Coastal Research* 17(3):531-543.

Decision Support Models: COSMO (Coastal zone Simulation MOdel)

Description	COSMO is a computer-based decision-support model that allows coastal zone managers to evaluate potential management strategies under different scenarios, including long-term climate change. COSMO demonstrates the main steps in the preparation, analysis and evaluation of Coastal Zone Management (CZM) plans. The program is an interactive tools that allow coastal zone managers to explore the impacts of development projects and environmental and coastal protection measures. It calculates 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 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	Useful as educational tools about relationship of adaptation to climate change in coastal zone management. Helps 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 unsuitable for analysis of actual management plans by itself. Might be used within other frameworks, such as studies based on the UNEP Handbook Methodology.
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 Available	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. Hoozemans et al. 1996. The coast in conflict. An interdisciplinary introduction to coastal zone management. CZM Publication 5, The Hague.
Applications	Used in training for CZM, including adaptation to climate change.
Contacts for Tools, Documentation, 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	Particularly useful in coastal settings with 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	Limited training is required, although background knowledge of physical, social, and economic characteristics of the area is helpful.
Training Available	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. Mimura, N., Harasawa, H., Hashimoto, H., Miyazaki, T., Nakai, S., Fukuwatari, K., Pacific Consultants Co Ltd, Yamada, K., Kawaguchi, S. (eds). 1996. *Data Book of Sea-Level Rise*. CGER, Tsukuba, 88 p. See also the web site http://www-cger.nies.go.jp
Applications	Used in several Pacific Island countries, including Fiji.
Contacts for Tools, Documentation, 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.

The South Pacific Island Methodology (SPIM) (cont.)

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 *Proceedings of the IPCC/WCC'93 Eastern Hemisphere Workshop*, *Tsukuba*, *3-6 August* 1993. R.F. McLean and N. Mimura (eds.). Department of Environment, Sport and Territories, Canberra, pp. 213-225. Nunn, P.D., A.D. Ravuvu, W. Aalbersberg, N. Mimura, and K. Yamada. 1994. *Assessment of Coastal Vulnerability and Resilience to Sea-Level Rise and Climate Change, Case Study: Yasawa Islands, Fiji — Phase II: Development of Methodology*. Environment Agency Japan, Overseas Environment Cooperation Centre Japan, South Pacific Regional Environment Programme. Nunn, P.D., A.D. Ravuvu, E. Balogh, N. Mimura, and K. Yamada. 1994. *Assessment of Coastal Vulnerability and Resilience to Sea-Level Rise and Climate Change, Case Study: Savai'i Island, Western Samoa — Phase II: Development of Methodology*. Environment Agency Japan, Overseas Environment Cooperation Centre Japan, South Pacific Regional Environment Programme. 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). Mimura, N. and H. Harasawa (eds.). 2000. *Data Book of Sea-Level Rise*. Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan.

RamCo and ISLAND MODEL

Description	RamCo and ISLAND MODEL are cell-based decision support tools 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 regional and global changes to boundary conditions, such as global trade patterns. These are the prototypes of more general information systems for decision support.
Appropriate Use	Because they are part of an evolving approach, they are excellent educational tools, although they have been used in analytical situations (see Applications below). Scope of applicability is currently limited by data availability, although new applications could be developed with the originators.
Scope	All locations where GIS data are 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 Guides are easy to follow without training — development of new applications would be much more difficult.
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 Available	Coastal Zone Management Centre, The Hague, The Netherlands, Tel: 31.70.3114.364.
Computer Requirements	Pentium or better, Windows 95 or better, Microsoft Excel (version 7.0), IDRISI for Windows. See page 15 of documentation.
Documentation	Uljee, I., G. Engelen, and R. White. 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. Uljee, I., G. Engelen, and R. White. 1996. ISLAND-Demo User Guide, Version 3, Research Institute for Knowledge Systems, P.O. Box 463, Tongersestraat 6, 6200 AL Maastricht, The Netherlands.
Applications	St. Lucia, Sulawesi.
Contacts for Tools, Documentation, 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.

RamCo and ISLAND MODEL (cont.)

References	Engelen, G., R. White, and I. Uljee. 1993. Exploratory modelling of socio-economic impacts of climatic change. In *Climatic Change in the Intra-Americas Sea.* G.A. Maul (ed.). Edward Arnold, London, pp. 350-368. Engelen, G., R. White, I. Uljee, and P. Drazen. 1995. Using cellular automata for integrated modelling of socio-environmental systems. *Environmental Monitoring and Assessment* 34:203-214. Engelen, G., R. White, I. Uljee, and S. Wargnies. 1996. Numerical modeling of small island socio-economics to achieve sustainable development. In *Small Islands: Marine Science and Sustainable Development*, *Coastal and Estuarine Studies* Volume 51, G.A. Maul, (ed.). American Geophysical Union, Washington, DC. pp. 437-463. White, R., G. Engelen, and I. Uljee. 2000. Modelling land use change with linked cellular automata and socio-economic models: A tool for exploring the impact of climate change on the island of St. Lucia. In *Spatial Information for Land Use Management*, M. Hill and R. Aspinall (eds.). Gordon and Breach, pp. 189-204. de Kok, J.L., G. Engelen, R. White, and H. Wind. 2001. Modelling land-use change in a decision-support system for coastal-zone management. *Environmental Monitoring and Assessment* 6:123-133.

Dynamic Interactive Vulnerability Assessment (DIVA)

Description	DIVA is a new tool for integrated assessment of coastal zones that will be released in late 2004. It is specifically designed to explore the vulnerability of coastal areas to sea level rise. It comprises a global database of natural system and socioeconomic factors, relevant scenarios, a set of impact-adaptation algorithms and a customized graphical-user interface. Factors that are considered include erosion, flooding salinisation and wetland loss. DIVA is inspired by the paper-based Global Vulnerability Assessment (Hoozemans et al., 1993), but it represents a fundamental improvement in terms of data, factors considered (which include adaptation) and use of PC technology.
Appropriate Use	DIVA is designed for national, regional and global scale analysis of coastal vulnerability, including consideration of broad adaptation issues.
Scope	All coastal areas at national, regional, and global scales.
Key Output	The impacts of sea level rise under a range of different user-defined scenarios, including some adaptation options.
Key Input	The user's chosen scenarios.
Ease of Use	The software is explicitly intended to be easy to use, and draws on extensive experience in graphical user interfaces.
Training Required	Designed to be used without significant training — an interested user should be able to explore this tool without any training.
Training Available	If required, contact DINAS-COAST consortium — see Contents below.
Computer Requirements	Windows 2000/XP, 2 GHz Pentium, 512 MB memory, 5 GB free hard drive.
Documentation	Included with the DIVA tool.
Applications	Still under development, but will be national to global in scope.
Contacts for Framework, Documentation, Technical Assistance	http://www.pik-potsdam.de/dinas-coast/ or http://www.dinas-coast.net. Richard Klein, Potsdam Institute for Climate Impact Research, Germany; e-mail: Richard.Klein@pik-potsdam.de. Robert Nicholls, University of Southampton, UK; e-mail: rjn@soton.ac.uk. Richard Tol, University of Hamburg, Germany; e-mail: tol@dkrz.de. Onno Kuik, Vrije Universiteit, The Netherlands; e-mail: onno.kuik@ivm.vu.nl. WL Delft Hydraulics, the Netherlands; e-mail: info@wldelft.nl.
Cost	Free download from http://www.dinas-coast.net.
References	Hoozemans, F.M.J., M. Marchand, and H.A. Pennekamp. 1993. *Sea Level Rise: A Global Vulnerability Assessment — Vulnerability Assessments for Population, Coastal Wetlands and Rice Production on a Global Scale.* Second revised edition, Delft Hydraulics and Rijkswaterstaat, Delft and The Hague, The Netherlands, xxiii+184 pp. Nicholls, R.J. 2002. Analysis of global impacts of sea-level rise: A case study of flooding. *Physics and Chemistry of the Earth* 27:1455-1466. Hinkel J. and R.J.T. Klein. 2003 DINAS-COAST: Developing a method and a tool for dynamic and interactive assessment. *LOICZ Newsletter*, No. 27 (June 2003), pp. 1-4. (downloadable at http://www.nioz.nl/loicz). Vafeidis, A., R.J. Nicholls, and L. McFadden. 2003. Developing a database for global vulnerability analysis of coastal zones: The DINAS-COAST project and the DIVA tool. In *Proceedings of EARSL* 2003, Ghent, Belgium, June 2003.

Shoreline Management Planning (SMP)

Description	Shoreline Management Planning is a generic approach to the strategic management of the combined hazards of erosion and flooding hazards in coastal areas, which are key concerns under climate change and sea level rise. New approaches to shoreline management have developed in the United Kingdom over the last 10 years. This involves dividing the coast of England and Wales into a series of natural units (cells and sub-cells). Based on these units, a number of shoreline management plans are then developed which collectively cover the entire coastal length. Each shoreline management plan further divides the coast based on land use and selects a series of strategic options to be applied over the next 50 to 100 years: (1) advancing the line; (2) holding the line; (3) managed realignment; (4) limited intervention; and (5) no active intervention. The practical implementation of these options is not directly considered — this is considered at lower levels of planning. Whatever is proposed must be consistent with a suite of Project Appraisal Guidance Notes (PAGN) that provide guidance (listed at http://www.defra.gov.uk/environ/fcd/pubs/pagn/default.htm). The Eurosion consortium have taken these approaches and developed them for application across the European Union (http://www.eurosion.org/).
Appropriate Use	SMP has been designed for developed countries with extensive coastal defense infrastructure. However, these approaches should find widespread application around the world's coasts, especially if slightly adapted to local circumstances. SMPs are designed as "living" plans, including regular update, so the whole process will stimulate the development of long-term coastal management appropriate to responding to climate change and sea level rise.
Scope	All coastal areas, typically at subnational to national scales pertinent to strategic flood and erosion management.
Key Output	Strategic approaches for flood and erosion management for the next 50 to 100 years.
Key Input	A range of information is required, including ideally historical shoreline change, contemporary coastal processes, coastal land use and values, and appropriate scenarios of change. However, the first generation of SMPs in England and Wales was conducted with incomplete datasets.
Ease of Use	The methods are designed assuming significant expertise and would be best implemented by consultants.
Training Required	With appropriate consultants this would not be necessary.
Training Available	None offered at present.
Computer Requirements	Depends on the approach adopted.
Documentation	DEFRA. 2001. *Shoreline Management Plans: A Guide for Coastal Defence Authorities*, Department for Environment, Food and Rural Affairs, 77 pp. (downloadable at http://www.defra.gov.uk/environ/fcd/pubs/smp/revisedsmpguidancefinal.pdf). See also http://www.eurosion.org/.
Applications	First generation of shoreline management plans of England and Wales developed using the guidance from MAFF et al. (1995). Second generation plans based on DEFRA (2001) are just beginning.

Shoreline Management Planning (SMP) (cont.)

Contacts for Framework, Documentation, Technical Assistance	DEFRA, Flood and Coastal Defence Division (http:/www.defra.gov.uk/). Stephane Lombardo, National Institute for Coastal and Marine Environment/RIKZ, Kortenaerkade, 1, 2500 EX The Hague, The Netherlands; Tel: + 31.70.3114.369; Fax: +31.70.3114.380; e-mail: S.Lombardo@rikz.rws.minvenw.nl.
Cost	Free download of DEFRA (2001) from http://www.defra.gov.uk/environ/fcd/pubs/smp/revisedsmpguidancefinal.pdf.
References	Ministry of Agriculture, Fisheries & Food (MAFF), Welsh Office, Association of District Councils, English Nature & National Rivers Authority. 1995. *Shoreline Management Plans: A Guide for Coastal Defence Authorities*. Ministry of Agriculture Fisheries & Food, London, 24 pp. Leafe, R., J. Pethick, and I. Townend. 1998. Realising the benefits of shoreline management. *Geographical Journal* 164:282-290. Burgess, K., H. Jay, and A. Hosking. 2002. FUTURECOAST: Predicting the Future Coastal Evolution of England and Wales. *Littoral 2002, The Changing Coast*, EUROCOAST, EUCC, Porto, Portugal, pp. 295-301.

4.4 Human Health Sector Tools

The health tools described in this compendium, listed in Table 4.4, differ significantly in their scope and application. Some facilitate the investigation of multiple or overall disease burden and how this burden responds to a number of environmental stressors, including climate change (MIASMA and Environmental Burden of Disease Assessment). Others are more narrowly focused and model the health impacts or transmission dynamics of particular diseases (CIMSiM and DENSiM, LymSim, and MARA LITe). They aid in identifying areas of high risk, and are particularly useful for areas currently endemic to diseases like malaria, dengue fever, and Lyme disease or in close proximity to such areas. Modeling adaptation strategies in the health sector is an emerging field, so the number of tools and approaches available explicitly designed for this purpose is still limited. The UNFCCC Guidelines is one such example. However, all the human health tools detailed in this section are suited to examining impacts of climate change on human health and potential adaptations.

Table 4.4. Tools covered in human health sector
MIASMA (Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)
Environmental Burden of Disease Assessment
CIMSiM and DENSiM (Dengue Simulation Model)
UNFCCC Guidelines: Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change
LymSiM
Mapping Malaria Risk in Africa (MARA) Low-end Information Tool (LITe)

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. Requires 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 Available	Dr. Pim Martens (see Contacts below).
Computer Requirements	Pentium PC, 16 MB RAM, Windows 95 or NT4 or higher. For hard drive installation: 20 MB 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. 1998. *Health and Climate Change: Modeling the Impacts of Global Warming and Ozone Depletion*. Earthscan Publications, London.
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, 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).

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

References	Martens, W. 1997. Health Impacts of Climate Change and Ozone Depletion: An Eco-Epidemiological Modelling Approach. Dept. Mathematics. Maastricht, University of Maastricht. 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. 1995. Climate change and vector-borne diseases: A global modelling perspective. *Global Environmental Change* 5(3):195-209. Martens, W.J.M., T.H. Jetten et al. 1997. Sensitivity of malaria, schistosomiasis, and dengue to global warming. *Climatic Change* 35:145-156.

Environmental Burden of Disease Assessment

Description	The global burden of disease attributable to climate change was recently estimated as part of a comprehensive World Health Organization (WHO) project. The project sought to use standardized methods to quantify disease burdens attributable to 26 environmental, occupational, behavioral, and life-style risk factors in 2000 and at selected future times up to 2030. The Environmental Burden of Disease (EBD) tools include guidelines on how to estimate the approximate magnitude of the health impacts of various environmental factors, including climate change, at national or regional level, to help determination of priorities for action.
Appropriate Use	An EBD assessment for climate change will indicate which impacts could be greatest and in which regions, and how much of the climate-attributable disease burden could be avoided by emissions reduction. It also will guide health-protective strategies.
Scope	An EBD assessment is usually conducted on a national or regional scale.
Key Output	Comparative risk assessment attempts to answer the following questions: 1) How much disease is caused by climate change (attributable burden of disease)? 2) How much could be avoided by making plausible reductions in the exposure (avoidable burden of disease)? The outputs can be defined by the user, but are usually in DALYs (disability adjusted life years) or avoided deaths that can be compared between populations and between specific health impacts of climate change.
Key Input	The following are needed to determine the amount of climate-sensitive disease that is attributable to climate change: 1) the baseline burden of climate-sensitive diseases, 2) the estimated increase in the risk of disease/disability per unit increase in exposure to climate change, and 3) the current or estimated future population distribution of exposure. The avoidable burden of climate-sensitive diseases is estimated by comparing projected burdens under alternative exposure scenarios. The global assessment used WHO estimates of the baseline burden of cardiovascular deaths associated with thermal extremes, diarrhea episodes, cases of malaria, malnutrition, and deaths due to natural disasters.
Ease of Use	Requires familiarity with comparative risk assessment methods, disease modeling, and estimation of DALYs.
Training Required	Depends on individual familiarity with comparative risk assessment methods, disease modeling, and estimation of DALYs.
Training Available	Occasional training workshops on EBD methods, by WHO.
Computer Requirements	Standard PC, GIS, and spreadsheet software; access to outputs of climate prediction models.
Documentation	Examples of global and regional assessments previously published by the WHO and Australian National University. Guidelines for comparative risk assessment methods have been published by WHO, with guidelines for national and regional assessments forthcoming in early 2004. The WHO guides on assessing the environmental burden of disease are available at http://www.who.int/quantifying_ehimpacts/publications/en/9241546204chap1.pdf. Publications on Environmental burden of disease are available at http://www.who.int/quantifying_ehimpacts/publications/en/. Research tools are available at http://www.who.int/research/en/.

Environmental Burden of Disease Assessment (cont.)

Applications	Can be used to estimate the burden of climate sensitive diseases that are most important nationally; identify populations that may suffer disproportionately due to low capacity to adapt to changing conditions, perhaps due to low socioeconomic status and poor public health systems. Because the assessment is still being drafted, no examples of its application yet exist.
Contacts for Framework, Documentation, Technical Assistance	Environmental Burden of Disease Assessment, Occupational and Environmental Health, Protection of the Human Environment (PHE), World Health Organization, 20, Avenue Appia, CH-1211 Geneva 27, Switzerland; e-mail: EBDAssessment@WHO.
Cost	Not identified.
References	WHO. 2003. The World Health Report 2002. World Health Organization, Geneva. McMichael, A.J. et al. 2003. Climate change. In *Global Burden of Disease*. C.J. Murray and A.D. Lopez (eds.). World Health Organization, Geneva.

CIMSiM and DENSiM (Dengue Simulation Model)

Description	CIMSiM is a dynamic life-table simulation entomological model that produces mean-value estimates of various parameters for all cohorts of a single species of Aedes mosquito within a representative 1 ha area (Focks et al., 1993a and b). For each cohort, depending on the life stage, CIMSiM maintains information on abundance, age, development with respect to temperature and size, weight, fecundity, and gonotrophic status. With few exceptions, the various processes are simulated mechanistically. The accounting is made dynamic by calculating on a daily bases the number of each cohort that will pass to the next age or stage as a function of a number of variables and relationships. For example, development times of eggs, larvae, pupae, and gonotrophic cycle are based on temperature using an enzyme kinetics approach. The bases of larval weight gain, food depletion, and fasting are differential equations modified to compensate for the influence of temperature. Fecundity is modeled as a function of pupal size, which in turn is a function of the recent history of larval abundance, food, temperature and, fasting in the larval habitat. All survivals are tied to temperature, and, for adults and eggs, saturation deficit as well; larval survival is also a function of fasting and fat body reserves. Because microclimate is a key determinant of survival and development for all stages, CIMSiM also contains an extensive database of daily weather information. DENSiM (Focks et al., 1995) is essentially the corresponding account of the dynamics of a human population driven by country- and age-specific birth and death rates. An accounting of individual serologies is maintained, reflecting infection and birth to seropositive mothers. The entomological factors passed from CIMSiM are used to create the biting mosquito population. The survival and emergence values dictate the dynamic size of the vector population within DENSiM while the gonotrophic development and weight estimates influence the rate at which these females bite. Temperature and titer of virus in the human influence the extrinsic incubation period in the mosquito; titer is also seen as influencing the probability of transfer of virus from human to mosquito. The infection model accounts for the development of virus within individuals and its passage between the vector and human populations.
Appropriate Use	The models can be used to 1) optimize dengue control strategies using multiple control measures; 2) develop transmission thresholds in terms of *Ae. aegypti pupae* per person as a function of temperature and herd immunity; and 3) evaluate the impact of climate change.
Scope	The models are site-specific and require local surveys and weather to parameterize them.
Key Output	Parameters estimated by DENSiM include demographic, entomologic, serologic, and infection information on a human age-class and/or time basis.
Key Input	A pupal/demographic survey is required to estimate the productivities of the various local water-holding containers. Daily weather is required — maximum/minimum temperature, rainfall, and saturation deficit.
Ease of Use	The front end of the models is Windows-based and easy to use. However, because the models are site-specific, there is a substantial upfront investment in parameterization.
Training Required	Usually, 3-4 days of training in the context of a grant where Dana A. Focks is either the PI or a collaborator with responsibilities for simulation analysis.
Training Available	Interested parties should contact Dana A. Focks.

CIMSiM and DENSiM (Dengue Simulation Model) (cont.)

Computer Requirements	IBM PC compatible computers are required. Memory 512 MB, processor speed useful, 1 GHz rough minimum.
Documentation	Documentation for the DOS versions is available from Dana A. Focks.
Applications	Use of the models has permitted the development of targeted source reduction/control strategies; WHO's TDR is now funding pilot evaluations in 10 countries. To project the impact of climate change on dengue prevalence in the Caribbean, Mexico, USA in Texas, and multiple locations in South and Central America, and Asia.
Contacts for Framework, Documentation, Technical Assistance	Dana A. Focks, Infectious Disease Analysis, P.O. Box 12852, Gainesville, FL 32604 USA; Tel: 352.375.3520; Fax: 352.372.1838; e-mail: DAFocks@ID-Analysis.com.
Cost	Depends on end user. Many dengue-endemic countries have copies.
References	Burke, D., A. Carmichael, D. Focks et al. 2001. *Under the Weather: Exploring the Linkages Between Climate, Ecosystems, Infectious Disease, and Human Health*. National Research Council, National Academy Press, Washington, DC 146 pp. Focks, D.A. 2003a. A Review of Entomological Sampling Methods and Indicators for Dengue Vectors. Tropical Disease Research, World Health Organization. Geneva. in press and on WHO/TDR web site. Focks, D.A. 2003b. Epidemiology. In Dengue. S.B. Halstead (ed.). Tropical Medicine-Science and Practice Series. G. Pasvol and S. Hoffman S, series eds. Imperial College Press. In press. Focks, D.A., R.J. Brenner, D.D. Chadee, and J. Trosper. 1998. The use of spatial analysis in the control and risk assessment of vector-borne diseases. *Am Entomologist* 45:173-183. Focks, D.A., R.A. Brenner, E. Daniels, and J. Hayes. 2000. Transmission thresholds for dengue in terms of Aedes aegypti pupae per person with discussion of their utility in source reduction efforts. *Am J Trop Med Hyg*. 62:11-18. Focks, D.A., E. Daniels, D.H. Haile, and J.E. Keesling. 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.H. Haile, E. Daniels, and G.A. Mount. 1993a. Dynamic life table model of a container-inhabiting mosquito, Aedes aegypti (L.) (Diptera: Culicidae). Analysis of the literature and model development. *J Med Entomol*. 30:1003-1017. Focks, D.A., D.H. Haile, E. Daniels, and G.A. Mount. 1993b. Dynamic life table model of a container-inhabiting mosquito, Aedes aegypti (L.) (Diptera: Culicidae). Simulation Results and Validation. *J Med Entomol*. 30:1018-1028. Jetten, T.H. and D.A. Focks. 1997. Changes in the distribution of dengue transmission under climate warming scenarios. *Am J Trop Med Hyg*. 57:285-297.

UNFCCC Guidelines: Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change

Description	Provides information on qualitative and quantitative methods of assessing human health vulnerability and public health adaptation to climate change. Objectives and the steps for assessing vulnerability and adaptation are described. For a range of health outcomes, methods are presented for evaluation of evidence that climate change could affect morbidity and mortality; projection of future impacts; and identification of adaptation strategies, policies, and measures to reduce current and future negative effects. The health outcomes considered are morbidity and mortality from heat and heat-waves, air pollution, floods and windstorms, and food insecurity; vector-borne diseases; water- and food-borne diarrheal diseases; and adverse health outcomes associated with stratospheric ozone depletion.
Appropriate Use	To conduct an assessment of current and future human health vulnerability of specific populations to climate change and to develop appropriate responses.
Scope	National or regional scales.
Key Output	Description of the current distribution and burden of climate-sensitive diseases; description of the adaptation baseline; evaluation of the health implications of the potential impact of climate change on other sectors; estimates of the future potential health impact of climate change using scenarios of future climate change, population growth, and other factors; and identification of additional adaptation measures to reduce current and future vulnerability.
Key Input	A basic assessment can be conducted using readily available information and data such as previous assessments, literature reviews by the IPCC and others, and available region-specific data. A more comprehensive assessment could include a literature search focused on the goals of the assessment, some quantitative assessment using available data, some quantification of effects, and a formal peer review of results. An even more comprehensive assessment could include a detailed literature review, collecting new data and/or generating new models to estimate impacts, extensive analysis of quantification and sensitivity, formal uncertainty analysis, and formal peer review.
Ease of Use	Can be used by anyone with familiarity with epidemiological and risk assessment methods.
Training Required	Little.
Training Available	In discussion for Central Asia.
Computer Requirements	Depends on level of assessment, from none to computers with adequate power to run models.
Documentation	See References below.
Applications	Assessment of the potential burden of climate-sensitive diseases and identification of response options to reduce vulnerability. Still being tested so examples of existing applications are few.

UNFCCC Guidelines: Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change (cont.)

Contacts for Framework, Documentation, Technical Assistance	Bettina Menne, WHO European Centre for Environment and Health, Via Francesco Crispi, 10 I-00187 Rome, Italy; e-mail: bme@who.it. Jacinthe Seguin, Climate Change and Health Office, Health Canada Ottawa, Ontario, Canada, http://hc-sc.gc.ca/cc. Sari Kovats, LSHTM, Dept of Public Health and Policy, Keppel St., London WC1E 7HT, England; e-mail: sari.kovats@lshtm.ac.uk. Kristie L. Ebi, Exponent, 1800 Diagonal Road, Suite 355, Alexandria, VA 22314, USA; e-mail: kebi@exponent.com
Cost	First 2000 copies free; additional reprints will have marginal costs.
References	WHO. 2003. Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change. World Health Organization, Geneva.

LymSiM

Description	LymSiM simulates the population dynamics of the blacklegged tick, *Ixodes scapularis*, and the dynamics of transmission of the Lyme disease agent, *Borrelia burgdorferi,* among ticks and vertebrate hosts. LymSiM models the effects of ambient temperature, saturation deficit, precipitation, habitat type, and host type and density on tick populations. The model accounts for epidemiological parameters, including host and tick infectivity, transovarial and transstadial transmission, such that the model realistically simulates the transmission of the Lyme disease spirochete between vector ticks and vertebrate hosts. The software features a dynamic life table model of *I. scapularis* with a weekly time step; rates of development, survival, fecundity, and host finding are based on weather or other environmental variables and vary with time. The relationships used were based on the literature and unpublished field studies.
Appropriate Use	Optimize control of Lyme disease and its vectors; and climate change impact studies.
Scope	The models are site-specific and require local surveys and weather data to parameterize them.
Key Output	Seasonal and geographical distributions of the Lyme disease agent and its vectors as a function of climate.
Key Input	Required inputs are 1) proportions of forested, meadow, and ecotone; 2) weekly average temperature, rainfall total, relative humidity, and saturation deficit; and 3) density of the four to six types of hosts.
Ease of Use	The model is Windows based and is easy to use.
Training Required	One or two days.
Training Available	Yes; contact Dana A. Focks at DAFocks@ID-Analysis.com.
Computer Requirements	IBM-compatible, minimal processor/memory required.
Documentation	Documentation exists for the earlier, DOS version. See Contacts below.
Applications	A principal use of LymSiM has been to simulate and optimize the effects of management technologies on populations of tick vector, *I. scapularis*, and *B. burgdorferi* in eastern North America. The model was used to evaluate area-wide acaricide treatments, acaricide self-treatment of white-footed mice and white-tailed deer, vegetation reduction, and white-tailed deer density reduction. Simulations demonstrated that area-wide acaricide, vegetation reduction, or a combination of these technologies would be useful for short-term seasonal management of ticks and disease in small recreational or residential sites. Moreover, acaricide self-treatment of deer appears to be the most cost-effective technology for use in long-term management programs in large areas. Simulation results also suggested that deer density reduction should be considered as a management strategy component. Finally, the model was used to develop integrated management strategies for operational tick and tick-borne disease control programs. Based on the previous studies, the U.S. Centers for Disease Control and Prevention used LymSiM to evaluated optimize various Lyme disease control techniques as a function of various degrees of compliance by the public involved in anti-tick measures. This assessment comparing the effectiveness of alternative community-based prevention strategies illuminates the limitations and distributive effects of interventions and helped clarify the actual available prevention options for community residents.

LymSiM (cont.)

Contacts for Framework, Documentation, Technical Assistance	Dana A. Focks, Infectious Disease Analysis, P.O. Box 12852, Gainesville, FL 32604 USA; Tel: 352.375.3520; Fax: 352.372.1838; e-mail: DAFocks@ID-Analysis.com.
Cost	A function of user and application.
References	Mount, G.A., D.G. Haile, and E. Daniels. 1997. Simulation of management strategies for the blacklegged tick (Acari: *Ixodidae*) and the Lyme disease spirochete, *Borrelia burgdorferi*. *J Med Entomol*. 34(6):672-663. Hayes, E.B., G.O. Maupin, G.A. Mount, and J. Piesman. 1999. Assessing the prevention effectiveness of local Lyme disease control. *J Public Health Manag Pract.* 5(3):84-92.

Mapping Malaria Risk in Africa (MARA) Low-end Information Tool (LITe)

Description	MARA is a biological model of *Falciparum* malaria transmission that sets decision rules which govern how minimum and mean temperature constrain the development of the parasite and the vector and how precipitation affects survival and breeding. MARA determined the decision rules by reviewing laboratory and field studies throughout Sub-Saharan Africa and looking at current malaria distribution maps. This biological model approximates the current boundaries of malaria distribution across the continent quite well. The model uses three variables to determine any geographic location's climatic suitability: mean monthly temperature, winter minimum temperature, and total cumulative monthly precipitation. An important distinction between this model and others is that the MARA decision rules were developed using fuzzy logic to resolve the uncertainty in defining distinct boundaries dividing malarious from nonmalarious regions. The MARA/ARMA decision rules stipulate that both temperature and precipitation have to be favorable at the same time of the year to allow transmission, and suitable conditions have to continue long enough for the transmission cycle to be completed. Five months were considered a sufficient length of time for conditions to be suitable for stable transmission. MARA LITe is a stand-alone query system of the MARA database. MARA LITe converts the MARA relational database (29 separate tables) into a flat structure.
Appropriate Use	MARA LITe can be used to create a baseline against which future increases or decreases in malaria can be quantified. These baselines can be used in conjunction with climate change scenarios to project possible populations at risk and future prevalence of *Falciparum* malaria for a given region.
Scope	MARA has not been validated outside of Sub-Saharan Africa.
Key Output	Calculations of populations at risk and graphic display of regions showing areas with potential *Falciparum* malaria transmission.
Key Input	Specified regions.
Ease of Use	Relatively easy to use.
Training Required	None.
Training Available	Comprehensive online help files exist for all aspects of the tool.
Computer Requirements	MARA is implemented in GIS format.
Documentation	See Contacts below.
Applications	Kleinschmidt, I., J. Omumbo, O. Briet, N. van de Giesen, N. Sogoba, N.K. Mensa, P. Windmeijer, M. Moussa, and T. Teuscher. 2001. An empirical malaria distribution map for West Africa. *Trop Med Int Health* 6:779-786. Gemperli A., P. Vounatsou, I. Kleinschmidt, M. Bagayoko, C. Lengeler, and T. Smith. 2004. Spatial patterns of infant mortality in Mali: The effect of malaria endemicity. *Am J Epidemiol* 159:64-72.
Contacts for Framework, Documentation, Technical Assistance	MARA/ARMA. 1998. *Towards an atlas of malaria risk in Africa.* Durban, South Africa. http://www.mara.org.za/lite/information.htm.

Mapping Malaria Risk in Africa (MARA) Low-end Information Tool (LITe) (cont.)

Cost	MARA LITe available in CD-ROM.
References	Craig M.H., R.W. Snow, and D. le Sueur. 1999. A climate-based distribution model of malaria transmission in sub-Saharan Africa. *Parasitology Today* 15:105-111. Snow R.W., M. Craig, U. Deichmann, and K. Marsh. 1999. Estimating mortality, morbidity, and disability due to malaria among Africa's non-pregnant population. *Bull. WHO* 77:624-640. Hartman, J., K.L. Ebi, J.K. McConnell, N. Chan, and J. Weyant. 2002. Climate suitability for stable malaria transmission in Zimbabwe under different climate change scenarios. *Global Change and Human Health* 3:2-14.

4.5 Terrestrial Vegetation Sector Tools

The terrestrial vegetation models presented in this compendium (listed in Table 4.5) represent a broad sample of the sorts of models that might be useful in considering the impacts of climate change as well as the potential for adaptation. Some of the models are global in scale (e.g., IBIS, IMAGE, and MC1, among others) while some are regional in their focus (e.g., Medrush). Some take a process based approach (e.g., LPJ, CASA, TEM, and CENTURY) while models such as AEZ rely on assessing the suitability of vegetation growth according to a number of productivity parameters. While most models allow for the investigation of a number of environmental parameters, models such as IMAGE were developed explicitly with climate change in question.

Table 4.5. Tools covered in terrestrial vegetation sector

LPJ (Lund-Postdam-Jena Model)
IBIS (Integrated BIosphere Simulator)
Medrush Vegetation Model
CENTURY
MC1
IMAGE (Integrated Model to Assess the Greenhouse Effect)
AEZ (Agro-ecological Zones) Methodology
CASA (Carnegie-Ames-Stanford Approach) Model
TEM (Terrestrial Ecosystem Model)

LPJ (Lund-Postdam-Jena) Model

Description	The LPJ model combines process-based, large-scale representations of terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges in a modular framework. Features include feedback through canopy conductance between photosynthesis and transpiration, and interactive coupling between these "fast" processes and other ecosystem processes, including resource competition, tissue turnover, population dynamics, soil organic matter and litter dynamics, and fire disturbance.
Appropriate Use	Photosynthesis, evapotranspiration, and soil-water dynamics are modeled on a daily time step, and vegetation structure and PFT population densities are updated annually.
Scope	Global at 0.5° latitude and longitude resolution.
Key Output	Vegetation structure, biomass carbon.
Key Input	Latitude, longitude, climate, soil texture, CO_2.
Ease of Use	Expert ecosystem vegetation scientist.
Training Required	Yes.
Training Available	No formal training offered.
Computer Requirements	Linux cluster.
Documentation	http://www.pik-potsdam.de/lpj/lpj_researchvt1.html - furtherinfo.
Applications	Maize simulations in Western Europe; other site specific crop simulations are in progress; also see results from Cramer et al.
Contacts for Framework, Documentation, Technical Assistance	Prof. Dr. I. Colin Prentice, Max Planck Institute for Biogeochemistry, Jena, Germany; Tel: +49.3641.643.774; Fax: +49.3641.643.775; e-mail: colin.prentice@bgc-jena.mpg.de.
Cost	Not identified.
References	Sitch, S., B. Smith, I.C. Prentice, A. Arneth, A. Bondeau, W. Cramer, J. Kaplan, S. Levis, W. Lucht, M. Sykes, K. Thonicke, and S. Venevski. 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ Dynamic Vegetation Model. *Global Change Biology* 9:161-185. Prentice, I.C., M. Heimann, and S. Sitch. 2000. The carbon balance of the terrestrial biosphere: Ecosystem models and atmospheric observations. *Ecological Applications* 10:1553-1573. Cramer, W. and 16 others. 2001. Global response of terrestrial ecosystem structure and function to CO_2 and climate change: Results from six dynamic global vegetation models. *Global Change Biology* 7:357-373.

IBIS (Integrated BIosphere Simulator)

Description	IBIS performs integrated assessments of water balance, carbon balance, and vegetation structure on both global and regional scales based on an integrated modeling approach that explicitly represents competition between plant functional types (competition for light and water); characterizes their responses to global change drivers (land use changes, climate variability and change, atmospheric CO2). IBIS is designed around a hierarchical conceptual framework, and includes several submodels (or "modules") that are organized with respect to their characteristic temporal scale: land surface processes (energy, water, carbon and momentum balance); soil biogoechemistry (carbon and nitrogen cycling from plant through soil); vegetation dynamics (plant competition for light, water, and eventually nutrients); vegetation phenology (based on a growing degree day approach); and atmospheric coupling (IBIS is now directly coupled to GENESIS and CCM3 GCMs).
Appropriate Use	IBIS represents a wide range of ecosystem and land surface processes in a single, physically consistent framework. In this way, IBIS can simulate the dynamic behavior of land surface and ecosystem processes, and their consequences for vegetation composition and structure.
Scope	Global; spatial: 0.5°, 1.0°, 2.0° and 4.0°; temporal: hourly.
Key Output	GPP, above and belowground NPP, NEP, fine root and heterotrophic respiration, nitrogen mineralization, latent, sensible heat, aet, evaporation, transpiration, snow temperature, extension and depth. Carbon and nitrogen: a) vegetation: fine roots, leaves, and wood for upper canopy (trees) and fine roots and leaves for lower canopy (shrubs and grasses); b) litter: above and belowground (fine root) separated in 3 distinct pools (decomposable, structural and resistant); c) soil organic matter: microbial biomass, protected and unprotected "slow" C pools, and passive C pool.
Key Input	Climatic, site, vegetation, soils and resolution (e.g., daily, monthly).
Ease of Use	Expert ecosystem vegetation scientist.
Training Required	Yes.
Training Available	No formal training offered.
Computer Requirements	High performance cluster.
Documentation	http://gaim.unh.edu/Structure/Intercomparison/EMDI/models/ibis.html.
Applications	Global climate impacts.
Contacts for Framework, Documentation, Technical Assistance	Jonathan Andrew Foley, Center for Sustainability and the Global Environment (SAGE), Institute for Environmental Studies, University of Wisconsin, 1225 West Dayton Street, Madison, Wisconsin 53706 USA; Tel: 608.265.9119; Fax: 608.265.4113; e-mail: jfoley@facstaff.wisc.edu.
Cost	Not provided.

IBIS (Integrated BIosphere Simulator) (cont.)

References	Foley, J.A., I.C. Prentice, N. Ramunkutty, S. Levis, D. Pollard, S. Sitch, and A. Haxeltine. 1996. An integrated biosphere model of land surface processes, terrestrial carbon balance and vegetation dynamics. *Global Biogeochemical Cycles* 10:603-628. Kucharik, C.J., J.A. Foley, C. Delire, V.A. Fisher, M.T. Coe, J. Lenters, C. Young-Molling, N. Ramankutty, J.M. Norman, and S.T. Gower. 2000. Testing the performance of a dynamic global ecosystem model: Water balance, carbon balance and vegetation structure. *Global Biogeochemical Cycles* 14(3):795-825. Delire, C. and J.A. Foley. 1999. Evaluating the performance of a land surface/ecosystem model with biophysical measurements from contrasting environments. *Journal of Geophysical Research (Atmospheres)* 104(D14):16:895-16,909.

Medrush Vegetation Model

Description	Landscape-scale model of vegetation structure and productivity, hydrology and soil erosion. Simulation of structure, productivity, and water relations of Mediterranean vegetation using a mechanistic (process-based) approach.
Appropriate Use	Applied to simulating the effects of recent historical changes in climate and CO2 in evergreen sclerophyllous shrubland.
Scope	Regional applications.
Key Output	Vegetation productivity, vegetation composition, soil erosion, and hydrology.
Key Input	Climatic, atmosphere CO_2, and soil texture data.
Ease of Use	Ecosystem-vegetation community expertise needed.
Training Required	Yes.
Training Available	Not indicated.
Computer Requirements	PC-based stand-alone.
Documentation	http://www.shef.ac.uk/aps/medveg.pdf.
Applications	Regional.
Contacts for Framework, Documentation, Technical Assistance	Professor Ian Woodward, Centre for Terrestrial Carbon Dynamics (CTCD), University of Sheffield, Dept. of Animal and Plant Sci., Alfred Denny Building, Western Bank, Sheffield S10 2TN, United Kingdom.
Cost	Not indicated.
References	Osborne, C.P., P.L. Mitchell, J.E. Sheehy, and F.I. Woodward. 2000. Modelling the recent historical impacts of atmospheric CO_2 and climate change on Mediterranean vegetation. *Global Change Biology* 6:445-458.

CENTURY

Description	This agroecosystem model simulates C, N, P, and S dynamics through an annual cycle over time scales of centuries and millennia. The producer submodel may be a grassland/crop, forest, or savanna system, with the flexibility of specifying potential primary production curves representing the site-specific plant community. CENTURY was especially developed to deal with a wide range of cropping system rotations and tillage practices for system analysis of the effects of management and global change on productivity and sustainability of agroecosystems. Simulation of complex agricultural management systems, including crop rotations, tillage practices, fertilization, irrigation, grazing, and harvest methods, is now possible. Note CENTURY is also described under agriculture.
Appropriate Use	Ecosystem application of climate and land use impacts.
Scope	Site to regional to global analysis of ecosystem biogeochemistry.
Key Output	Plant productivity, crop yields, vegetation carbon and nitrogen, N mineralization, evapotranspiration, soil water content, soil organic matter carbon and nitrogen content.
Key Input	Climate, soil texture, land use management.
Ease of Use	Ecosystem biogeochemistry expertise needed.
Training Required	Yes.
Training Available	Yes.
Computer Requirements	PC-based stand alone version, Linux cluster for regional simulations.
Documentation	http://www.nrel.colostate.edu/projects/century5/. http://www.nrel.colostate.edu/projects/century5/reference/index.htm. http://www.nrel.colostate.edu/projects/century/.
Applications	Site level to regional simulations of climate and land use effects on ecosystem biogeochemistry and water dynamics.
Contacts for Framework, Documentation, Technical Assistance	Dr William Parton, NREL at Colorado State University, 1499 Campus Delivery Fort Collins, CO 80523-1499, USA; Tel: 970.491.1987; e-mail: billp@nrel.colostate.edu. Cindy Keough, Natural Resource Ecology Laboratory**,** Colorado State University**,** Fort Collins, CO 80523-1499 USA; Tel: 970.491.2195; Fax: 970.491.1965; e-mail: cindyk@nrel.colostate.edu.
Cost	Not identified.

CENTURY (cont.)

References	Kelly, R.H., W.J. Parton, G.J. Crocker, P.R. Grace, J. Klír, M. Körschens, P.R. Poulton, and D.D. Richter. 1997. Simulating trends in soil organic carbon in long-term experiments using the Century model. *Geoderma* 1258. Ojima, D.S., W.J. Parton, D.S. Schimel, T.G.F. Kittel, and J.M.O. Scurlock. 1993. Modeling the effects of climatic and CO_2 changes on grassland storage of soil C. *Water, Air, and Soil Pollution* 70:643-657. Parton, W.J., D.S. Schimel, D.S. Ojima, and C.V. Cole. 1994. A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. Pages 147-167 *in* R.B. Bryant and R.W. Arnold, editors. Quantitative modeling of soil forming processes. SSSA Spec. Publ. 39. ASA, CSSA and SSA, Madison, WI, USA. VEMAP et al., J.M. Melillo, J. Borchers, J. Chaney, H. Fisher, S. Fox, A. Haxeltine, A. Janetos, D.W. Kicklighter, T.G.F. Kittel, A.D. McGuire, R. McKeown, R. Neilson, R. Nemani, D.S. Ojima, T. Painter, Y. Pan, W.J. Parton, L. Pierce, L. Pitelka, C. Prentice, B. Rizzo, N.A. Rosenbloom, S. Running, D.S. Schimel, S. Sitch, T. Smith, and I. Woodward. 1995. Vegetation/ecosystem modeling and analysis project: comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. *Global Biogeochemical Cycles* 9 :407-437.

MC1

Description	MC1 consists of three linked modules simulating biogeography, biogeochemistry, and fire disturbance. The main functions of the biogeography module are to (1) predict the composition of deciduous/evergreen tree and C3/C4 grass lifeform mixtures, and (2) classify the predicted biomass from the biogeochemistry module into different vegetation classes. The biogeochemistry module simulates monthly carbon and nutrient dynamics for a given ecosystem. Above- and below-ground processes are modeled in detail, and include plant production, soil organic matter decomposition, and water and nutrient cycling. Parameterization of this module is based on the lifeform composition of the ecosystems, which is updated annually by the biogeography module.
Appropriate Use	Climate change effects on vegetation changes.
Scope	Regional to global.
Key Output	Vegetation structure, fire events, plant productivity, vegetation carbon, soil carbon and nitrogen, evapotranspiration.
Key Input	Monthly precipitation, mean monthly average minimum and maximum temperatures, vapor pressure, wind speed, solar radiation, soil depth, soil texture, bulk density.
Ease of Use	Ecosystem and vegetation science expertise.
Training Required	Yes.
Training Available	See Contacts below.
Computer Requirements	Linux cluster or multiple processor.
Documentation	http://www.fsl.orst.edu/dgvm/mcgtr508.pdf.
Applications	Regional to global applications.
Contacts for Framework, Documentation, Technical Assistance	Ronald P. Neilson, BioClimatologist, USDA Forest Service, Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331 USA; Tel: 541.750.7303; e-mail: rneilson@fs.fed.gov.
Cost	Depends on application.
References	Bachelet, D., J.M. Lenihan, C. Daly, and R.P. Neilson. 2000. Climate, fire and grazing effects at Wind Cave National Park, SD. Ecological Modelling 134(2-3):229-244. Lenihan, J.M., C. Daly, D. Bachelet, and R.P. Neilson. 1998. Simulating broad-scale fire severity in a dynamic global vegetation model. *Northwest Science* 72:91-103. Bachelet, D., J.M. Lenihan, C. Daly, R.P. Neilson, D.S. Ojima, and W.J. Parton. 2001. MC1. A dynamic vegetation model for estimating the distribution of vegetation and associated ecosystem fluxes of carbon, nutrients and water. Technical Documentation Version 1.0. General Technical Report PNW-GTR-508. Corvallis, OR. USDA Forest Service, Pacific Northwest Research Station. Daly, C., D. Bachelet, J.M. Lenihan, R.P. Neilson, W.J. Parton, and D. Ojima. 2000. Dynamic simulation of tree-grass interactions for global change studies. *Ecological Applications* 10(2):449-469.

IMAGE (Integrated Model to Assess the Greenhouse Effect)

Description	IMAGE 2.0 was developed at RIVM in the Netherlands (Alcamo, 1994). It takes a global approach with the entire earth system as the subject of investigation. Its main use is scenario analysis of the issue of anthropogenic climate change due to the greenhouse effect. It is *Integrated* because it is designed to simulate the dynamics and interconnections between three major subsystems of the globe, namely, climate, biosphere, and society.
Appropriate Use	Land use and climate change effects on land productivity.
Scope	Global and national level responses.
Key Output	Cumulative greenhouse gas emissions, the resulting atmospheric concentrations, global warming, sea level rise, changing patterns of land use and cover, agricultural impacts, ecosystem risks, and also the costs of policies for emissions reduction or control.
Key Input	Climate, soil, land use and cover, regional demands for cropland and rangeland and fuelwood demand, and "local" potential for land.
Ease of Use	Expertise of ecosystem and land use science.
Training Required	Yes.
Training Available	No formal training offered.
Computer Requirements	PC-based.
Documentation	http://www.zit.tu-darmstadt.de/.
Applications	Regional and global use.
Contacts for Framework, Documentation, Technical Assistance	Joseph Alcamo, Environmental Systems Engineering, Executive Director, Center for Environmental Systems Research, Kurt-Wolters-Straße 3, Room 2116, 34109 Kassel, Germany; Tel: +49.561.804.3898; Fax: +49.561.804.3176; e-mail: alcamo@usf.uni-kassel.de.
Cost	Not specified.
References	Alcamo, Joseph (ed.). 1994. *IMAGE 2.0: Integrated Modeling of Global Climate Change*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

AEZ (Agro-ecological Zones) Methodology

Description	The Food and Agriculture Organization of the United Nations (FAO) with the collaboration of the International Institute for Applied Systems Analysis (IIASA), has developed this system, which enables rational land-use planning on the basis of an inventory of land resources and evaluation of biophysical limitations and potentials. Recent availability of digital global databases of climatic parameters, topography, soil and terrain, vegetation, and population distribution has called for revisions and improvements in calculation procedures and in turn has allowed for expanding assessments of AEZ crop suitability and land productivity potentials to temperate and boreal environments.
Appropriate Use	Climate change analysis of crop production. It is recommended that users access model results.
Scope	Global to regional.
Key Output	Maximum potential and agronomically attainable crop yields for basic land resources units (usually grid-cells in the recent digital databases).
Key Input	Climate, topography and soil characteristics, and is to a large extent determined by demographic, socioeconomic, cultural, and political factors, such as population density, land tenure, markets, institutions, and agricultural policies.
Ease of Use	Expertise in crop systems.
Training Required	Yes.
Training Available	See Contacts below.
Computer Requirements	Web-based PC tools.
Documentation	http://www.iiasa.ac.at/Research/LUC/GAEZ/index.htm?sb = 6.
Applications	Climate change assessments of agricultural production.
Contacts for Framework, Documentation, Technical Assistance	Gunther Fischer, International Institute for Applied Systems Analysis (IIASA), A-2361 Laxenburg, Austria; Tel: +43.2236.807.0; Fax: +43.2236.71.313; e-mail: fisher@iiasa.ac.at.
Cost	Depends on application.

References	Fischer, G. and H.T. Van Velthuizen. 1996. Climate Change and Global Agricultural Potential Project: A Case Study of Kenya. International Institute for Applied Systems Analysis, Laxenburg, Austria, 96 pp. Fischer, G and G.K. Heilig. 1997. Population momentum and the demand on land and water resources. *Phil. Trans. R. Soc. Land.* B 352:869-889. Fischer, G. and H.T. van Velthuizen. 1999. Agro-ecological zones of China, the former Soviet Union and Mongolia. International Institute for Applied Systems Analysis, Laxenburg, Austria. Batjes, N.H., G. Fischer, F.O. Nachtergaele, V.S. Stolbovoi, and H.T. van Velthuizen. 1997. Soil Data Derived from WISE for Use in Global and Regional AEZ Studies. FAO/IIASA/ ISRIC Report IR-97-025. International Institute for Applied Systems Analysis, Laxenburg, Austria.

CASA (Carnegie-Ames-Stanford Approach) Model

Description	Calculation of monthly terrestrial NPP is based on the concept of light-use efficiency, modified by temperature and moisture stress scalars. Soil carbon cycling and Rh flux components of the model are based on a compartmental pool structure, with first-order equations to simulate loss of CO2 from decomposing plant residue and surface soil organic matter (SOM) pools. Model outputs include the response of net CO2 exchange and other major trace gases in terrestrial ecosystems to interannual climate variability (1983 to 1988) in a transient simulation mode.
Appropriate Use	Climate change analysis of ecosystem productivity.
Scope	Global to regional.
Key Output	Global gridded estimates of primary production, above and below ground biomass, leaf area index (LAI), and trace gas fluxes.
Key Input	Air surface temperature and precipitation are used together with long-term (30-year) mean values, and surface solar irradiance measurements.
Ease of Use	Expertise of ecosystem and biogeochemistry science.
Training Required	Yes.
Training Available	No formal training offered.
Computer Requirements	High end workstation.
Documentation	http://geo.arc.nasa.gov/sge/casa/index4.html.
Applications	Estimate of current ecosystem productivity.
Contacts for Framework, Documentation, Technical Assistance	Christopher Potter, Ecosystem Science and Technology, NASA Ames Research Center, Moffett Field, CA USA; Tel: 650.604.6164; Fax: 650.604.4680; e-mail: cpotter@gaia.arc.nasa.gov.
Cost	Not specified.
References	Potter C.S. and S.A. Klooster. 1997. Global model estimates of carbon and nitrogen storage in litter and soil pools: Response to change in vegetation quality and biomass allocation. *Tellus* 49B(1):1-17. Potter, C.S., E.A. Davidson, and L. Verchot. 1996. Estimation of global biogeochemical controls and seasonality in soil methane consumption. *Chemosphere* 32(11):2219- 2246. Potter, C.S., S.A. Klooster, and V. Brooks. 1999. Interannual variability in terrestrial net primary production: Exploration of trends and controls on regional to global scales. *Ecosystems* 2(1):36-48. Potter, C.S., P.A. Matson, P.M. Vitousek, and E.A. Davidson. 1996. Process modeling of controls on nitrogen trace gas emissions from soils world-wide. *J. Geophys. Res.* 101:1361-1377.

TEM (Terrestrial Ecosystem Model)

Description	The TEM is a process-based ecosystem model that describes carbon and nitrogen dynamics of plants and soils for terrestrial ecosystems of the globe. The TEM uses spatially referenced information on climate, elevation, soils, vegetation, and water availability as well as soil- and vegetation-specific parameters to make monthly estimates of important carbon and nitrogen fluxes and pool sizes of terrestrial ecosystems. The TEM operates on a monthly time step and at a 0.5° latitude/longitude spatial resolution.
Appropriate Use	Regional to global simulation of climate effects on ecosystem dynamics.
Scope	Regional to global.
Key Output	GPP, NPP, evapotranspiration, soil carbon and nitrogen, vegetation carbon and nitrogen.
Key Input	Vegetation, soil texture, elevation, solar radiation, precipitation, air temperature.
Ease of Use	Expertise in ecosystem science and biogeochemistry.
Training Required	Yes.
Training Available	See Contacts below.
Computer Requirements	High-end workstation.
Documentation	http://www.mbl.edu/eco42/.
Applications	Examined the time-dependent responses of terrestrial carbon storage and the net carbon exchange with the atmosphere as influenced by historical climate CO_2, land use and soil thermal regime.
Contacts for Framework, Documentation, Technical Assistance	Jerry M. Melillo, A. David McGuire, David W. Kicklighter, Yude Pan, Hanqin Tian, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543 USA; e-mails: jmelillo@lupine.mbl.edu, ffadm@aurora.alaska.edu, dkick@mbl.edu.
Cost	Not specified.
References	Pan, Y., A.D. McGuire, J.M. Melillo, D.W. Kicklighter, S. Sitch, and I.C. Prentice. 2002. A biogeochemistry-based dynamic vegetation model and its application along a moisture gradient in the continental United States. *Journal of Vegetation Science* 13:369-382. Tian, H., J.M. Melillo, D.W. Kicklighter, S. Pan, J. Liu, A.D. McGuire, and B. Moore III. 2003. Regional carbon dynamics in monsoon Asia and its implications for the global carbon cycle. *Global and Planetary Change* 37:201-217. McGuire, A.D., C. Wirth, M. Apps, J. Beringer, J. Clein, H. Epstein, D.W. Kicklighter, J. Bhatii, F.S. Chapin III, B. de Groot, D. Efremov, W. Eugster, M. Fukuda, T. Gower, L. Hinzman, B. Huntley, G.J. Jia, E. Kasischke, J.M. Melillo, V. Romanovsky, A. Shvidenko, E. Vaganov, and D. Walker. 2002. Environmental variation, vegetation distribution, carbon dynamics, and water/energy exchange in high latitudes. *Journal of Vegetation Science* 13:301-314.