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Item 8 (d) of the provisional agenda

METHODOLOGICAL ISSUES

METHODS AND TOOLS TO EVALUATE IMPACTS AND ADAPTATION

Submissions from Parties

Note by the secretariat

1. At its eleventh session, the Subsidiary Body for Scientific and Technological Advice (SBSTA) took note of the information on the web site of the secretariat related to decision tools, models and methodologies to evaluate impacts and adaptation strategies. It invited Parties, international organizations and other organizations to submit additional information electronically to the secretariat, particularly on new decision tools, models and methodologies, using the format on the web site, by 15 February 2000 (FCCC/SBSTA/1999/14, para. 68 (a)).

2. Submissions have been received from two Parties.[*] In accordance with the procedure for miscellaneous documents, these submissions are attached and are reproduced in the language in which they were received and without formal editing.

3. The secretariat has also received 12 submissions from non-governmental organizations on methods and tools to evaluate impacts and adaptation. It is the practice of the secretariat not to reproduce information submitted by non-governmental organizations. However, Parties may wish to request copies of these submissions directly from the UNFCCC secretariat.

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[*] In order to make these submissions available on electronic systems, including the World Wide Web, these contributions have been electronically scanned and/or retyped. The secretariat has made every effort to ensure the correct reproduction of the texts as submitted.

FCCC/SBSTA/2000/MISC. 5

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PAPER NO. 1: CHINA

In response to the request of FCCC/SBSTA/1999/L.12, China's some organizations: Agrometeorology Institute of CAAS, National Climate Center of CMA, Geography Institute of CAS, China Institute for Marine affairs, Water Resources Information Center of MWR, would submit the attached information of tools and models on the impacts and adaptation assessment. The tools and models on the impacts and adaptation assessment contained in the submitted information may be upgraded and improved if necessary.

Climate Scenarios/Prediction System

Description	Climate scenarios/predictions system is a modeling system for the predictions of climate change in future over a regional domain due to both natural change and man-made change. Based on the observed climate data, the climate change in future for several decades can be predicted by using both statistical modes such as time series analyses and simple models such as energy balance model. In the another hand, climate scenarios over a region in future due to the human activities as simulated by one or several GCMs are able to be predicted. Assessments and evaluations can also be conducted by this system. This is a useful tool to make the strategy decisions for climate and vulnerable research, as well as policy-makers in the world and China.
Appropriate Use	This system is important and often to be used for both vulnerable/adaptation studies and policy-makers to make the strategy decision. Scientists and policy-makers can understand the climate change in future over a regional domain using this system.
Scope	This system will be used by the world, especially for the countries in the Asian and Pacific regions.
Key Output	Scenarios of climate change in future due to both natural and man-made changes can be predicted. Methodology of climate detection and evaluation can be given.
Key Input	Regional climate data such as temperature and precipitation for several decades or longer time; The international and domestic GCMs' simulations due to human activities can be used.
Ease of Use	Easy to apply by the document of guidance.
Training Required	one week to study how to use it.
Training Offered	Training course
Computer Requirements	PC (personal computers)
Documentation	see references
Applications	Prediction of climate change for the next 50 years over China, Beijing, China, 1992-1996; Country Study USA/China, 1996;
Contacts for Tools, Documentation, and Technical Assistance	Zhao Zong-ci, National Climate Center(NCC), Baishiqiaolu, No.46, Beijing, 100081, P.R.China, E-mail: zhaozc@sun.ihep.ac.cn
Cost	**Varies, contact NCC for information**
References	[1]S.-W.Wang and Z.-C.Zhao, 1995, A study of the trend of climate change during the period of next 50 years, Quar. J. of Appl. Meteorol., 6, 333-342 (in Chinese). [2]Zhao Zong-ci, 1996, Impacts of greenhouse effects on climate change over China for the next 50 years, Climate Change and Simulations (III), eds by 85-913-02, China Meteorological Press, Beijing, China, 170-178 (in Chinese).

RCM/CN (Regional Climate Model over China)

Description	RCM/CN is a regional climate model over China for the predictions of climate change in future over a regional domain due to both natural change and man-made change. This model was developed by Chinese scientists based on the RegCM2 (F.Giorgi et al., 1993). Because the model is a common tool, it is interesting not only for the Chinese policy-makers and scientists, but also for the world, especially for the Asian and Pacific countries. The regional climate model focused on the regional issues such as changes of extreme warm/cold, floods/droughts, typhoons and other climate anomalies.
Appropriate Use	This model is important and often to be used for both vulnerable/adaptation studies and policy-makers to make the strategy decision. Scientists and policy-makers can understand the climate change in future over a regional domain using this model, especially for the regional extreme events .
Scope	This system will be used by the world, especially for the countries in the Asian and Pacific regions.
Key Output	Scenarios of climate change in future over a region due to both natural and man-made changes can be predicted in detail, especially regional extreme events.
Key Input	Climate data for driving the regional model by a GCM.
Ease of Use	Scientists must study this model for a longer time.
Training Required	one month to learn how to use it.
Training Offered	Training course
Computer Requirements	High quality computer workstations and PC computers
Documentation	see references
Applications	Intercomparisons of regional climate modeling over East Asia, DOE(US)/CMA(China), 1995-2005; Short-term climate predictions system, Beijing, China, 1996-2000.
Contacts for Tools, Documentation, and Technical Assistance	Zhao Zong-ci, National Climate Center(NCC), Baishiqiaolu, No.46, Beijing, 100081, P.R.China, e-mail: zhaozc@sun.ihep.ac.cn
Cost	**Varies, contact NCC for information**
References	[1] Zhao Zongci and Luo Yong, 1997, Advances in regional climate modeling since 1990, Acta Meteorologica Sinica, 11, 385-406 (in English). [2] Zhao Zong-ci and Luo Yong, 1999, Investigations of application for the regional climate model over East Asia, Chinese J. of Atm. Sci., 23, 522-532 (in Chinese).

Productivity Function Model

Description	The productivity function model is a statistical model. It simulates both the effects of natural factors such radiation, temperature and water, and the effects of many agricultural management measures such as irrigation condition, labor, modernization condition, fertilizer condition and pesticide cost etc. on crop production.
Appropriate Use	The model can be used to analyses the effects of natural conditions such as climate, soils and water, agricultural management measures, as well invest on crop productivity, and further for scientists and policy-makers to explore the adaptation strategy and its cost to climate change.
Scope	All locations, site-specific, Agricultural sector
Key Output	Crop yields under different national conditions and management measures.
Key Input	crop potential yield, agricultural invest, agricultural management measures such as irrigation price, labor force, modernization condition, fertilizer price and pesticide cost etc.
Ease of Use	Easy to apply by the document of guidance.
Training Required	one week to study how to use it.
Training Offered	Training course
Computer Requirements	PC (personal computers)
Documentation	see references
Applications	Used to assessing the agricultural adaptation strategy to climate change and its cost in China
Contacts for Tools, Documentation, and Technical Assistance	Prof. Lin Erda, Drs. Tao Fulu & Ju Hui Agrometeorology Institute(AMI), Chinese Academy of Agricultural Sciences, Baishiqiao Rd, No.30, Beijing, 100081, P.R.China.Tel: +86-010-68975410; Fax: +86-010-68975410/5409. E-mail: Lined@ns.ami.ac.cn
Cost	US $ 1,800 for a training course, contact AMI for information
References	[1] Lin Erda, Zhang Huxuan, Wang jinghua (eds). 1997. Simulating impacts of climate change on Chinese agriculture. Chinese agricultural science and technology press. [2] Research Team of China Climate Change Country Study (ed.). 1999. China Climate Change Country Study, Tsinghua University Press.

Process Weather Transfer Tools for Crop Models: The Chinese Weather Generator

Description	The Chinese Weather Generator (CWG) is a program for generating randomly daily maximum & minimum temperature, precipitation, and solar radiation data of a long time-series for the study sites. CWG was developed by the same methodology used in WGEN. In order to define the model parameters in CWG, long term of observed daily maximum & minimum temperature, precipitation and solar radiation were collected, more data longer, more result certainty.
Appropriate Use	In assessment of climate change impacts on crop yield, the crop models mostly need daily weather data, but generally, there are not enough confidence daily weather data for scientist to use, as for observation data that is too short to use for long term weather results. The Chinese Weather Generator can help to produce the randomly daily data for at least 200 years.
Scope	All locations; agricultural sector; site-specific; national or regional level
Key Output	Daily weather data more than two hundred sample years can be generated by CWG
Key Input	Using monthly GCM scenarios, history daily weather data
Ease of Use	Skilled personnel for DOS or WINDOWS operation system can run it in 1-2 days. For future applying, need much time committed.
Training Required	Applicant must have bachelor degree and can use basic DOS or Windows operation
Training Offered	Governmental, education institution and other organization provide funding for this training.
Computer Requirements	The model can be run on various kind of microcomputer above Intel 586. The operation system can be Windows 95 or 98, or DOS environment.
Documentation	Lin Erda, Zhang Houxuan , Wang Jinhua The impacts simulation of global climate change on China agricultureChina Agricultural Science and Technology Press, Beijing, 1997
Applications	Used for the research of climate change impacts on crops in China
Contacts for Tools, Documentation, and Technical Assistance	Prof. Lin Erda, Drs Tao Fulu & Ju Hui. Agrometeorology Institute(AMI) of Chinese Academy of Agricultural Science.100081, Beijing, China Tel: (8610) 68919333 Fax: (8610) 68975410. E-mail: Lined@ns.ami.ac.cn
Cost	US$ 2100 for a training course, contact AMI for information
References	China Climate Change Country Study, 1999, Tsinghua University Press

Process Forest Models: Geographical information system for the impact of climate change on forest (GIS/ICCF)

Description	GIS/ICCF uses an expanded database management system as the kernel of data support, and also use object-oriented, event-driven programming methods, object embedding and linking mechanism to systematically analysis the forest change with climate scenarios. It can be considered as an expert system for forest prediction and management.
Appropriate Use	Assessing the change of forest in species, distribution and area in response to the impact of global climate change; Determining and measuring the vulnerable forest area in response to the impacts of global climate change.
Scope	For regional or national level
Key Output	Dynamically simulating the process of forest community in response to climate change.
Key Input	It includes seven modules such as attribute data management, spatial data management, climate parameter calculation, transformation of data with different formats, projection transfer of spatial data with different coordinate systems, modeling tools and thematic models. The database include present climate data, future climate change scenarios, and data on terrain, soil, vegetation, forests and political boundaries.
Ease of Use	All forest researchers skilled with GIS operation can use it easily.
Training Required	Applicant must have forest knowledge and know basic operation process for GIS.
Training Offered	Geographic Institute of CAS can provide training if the applications apply the GIS/ICCF tools. For group training, it needs financial support from governmental, education or other institution.
Computer Requirements	The operation environment is Windows95, Windows 98, or windows NT.
Documentation	Contacted with the responsible person as below.
Applications	For the research of climate change impact on forest, agriculture, coastal zone *et al*.
Contacts for Tools, Documentation, and Technical Assistance	Prof. Xu Deying Forest Ecology and Environment laboratory, Chinese Academy of Forest Science. 100091, Wanshoushan, Beijing, China Tel: (8610)62889553 Fax: (8610) 62881937 E-mail: deyingxu@fee.forestry.ac.cn
Cost	**About US$ 1700 (not include GIS)**
References	China climate Change Country Study,1999, Tsinghua University Press

Historical Disaster Analogue: HDA

Description	Historical Disaster Analogue (HDA) is an analysis method using historical records (eg. drought or flood events and their impacts in warm conditions) as an analogue of possible future conditions. HDA could assist the user to analyze the possibility for the disaster and its impacts while global warming.
Appropriate Use	This model provides a useful analysis in ecosystem assessment impacts of climate change and adaptation measures for country and region level studies.
Scope	All locations; all sectors; national or site-specific
Key Output	The possibility for the disaster and its impacts
Key Input	The historical climatic data, the historical disastrous data and future climate scenarios
Ease of Use	Easy to use, although the robustness of the analysis depends on the extent of the user's knowledge of the situations being analyzed.
Training Required	Requires a background of the impact assessment issue being analyzed.
Training Offered	Questions and more information can be directed to Jingyun Zheng and Piyuan Zhang (See below).
Computer Requirements	Hardware and Software for GIS and SPSS
Documentation	Piyuan Zhang et al., 1996, The Climate Change in China during Historical Times.
Applications	Used in China
Contacts for Tools, Documentation, and Technical Assistance	Jingyun Zheng, Piyuan Zhang, Institute of Geography, Chinese Academy of Sciences, Beijing 100101, China. Tel: 86-10-64889499, Fax: 86-10-64851844 E-mail: geqs@dls.iog.ac.cn
Cost	Low cost to obtain documentation
References	Climate Change in China during Historical Times, 1996, Piyuan Zhang, Shandong Science and Technology Press, 195-509.

Vegetation Model: CVRM

Description	Climate Vegetation Response Model (CVRM) is a comprehensive assessment model evaluating the potential impact of climate change on vegetation types, distribution, area and biomass. CVRM assists the user in evaluating future impact of elevated CO_2 and climate change on vegetation (forests, steppes, deserts, crops etc.) and potential adaptation options.
Appropriate Use	This model provides the initial and basic analysis in any ecosystem assessment impacts of climate change and adaptation measures for country and region level studies.
Scope	Regional, national or global analysis.
Key Output	Change of vegetation types, horizontal and vertical distributions and area.
Key Input	Present climate data, future climate scenarios and data of terrain, soil and vegetation.
Ease of Use	The simulated distributions of vegetation can be modified when they are applied to different countries or regions.
Training Required	Requires some knowledge of the vegetation types, distribution and discrimination technique.
Training Offered	Questions and more information can be directed to Xuemei Shao (see below).
Computer Requirements	PC windows 95 or NT.
Documentation	Research Team of China Climate Change Country Study, 1999, China Climate Change Country Study.
Applications	Used in China.
Contacts for Tools, Documentation, and Technical Assistance	Kerang Li, Xuemei Shao and Yufeng Chen, Institute of Geography, Chinese Academy of Sciences, Beijing, China. Tel: 86 –10 –64889602, Fax: 86-10-64851844 E-mail: krli@public.east.net.cn, shaoxm@dls.iog.ac.cn.
Cost	Relatively low cost to obtain model documentation.
References	*China Climate Change Country Study*, 1999, Research Team of China Climate Change Country Study, Tsinghua University Press, P130-158. *Acta Geographica Sinica*, 1996, vol. 51 supplement, P26-39.

Predicting model for sea level change along Chinese

Description	In the design of predicting model for sea level change along Chinese coast has been taken into consideration both the global sea level and the features of the relative rise or fall of the coastal sea level, the former is characteristic of the estimated value of global sea level rise caused by climate change effect and the latter of the relative sea level change attributable to such factors as the vertical crust movement and the ground subsidence in various coastal areas. The predicting value of global sea level rise can be obtained from the predicting equation for the global sea level change proposed by Wigley T.M.L. and Raper S.C.B.(1992). The predicting value of the relative sea level change based on the calculation of difference between the rising rate of relative sea level in a certain region and the rate of global sea level rise.
Appropriate Use	Used for coastal and regional analysis, and can be used for the risk evaluation to analyze a range of possible adaptation options.
Scope	Coastal zone especially for low-lying vulnerable coastal area.
Key Output	Predicted values of future(2030,2050,2100) sea level rise in 5 regions(liaoning-Tianjin coast, Eastern and Southern Shandong Peninsula coast, Jiangsu-Eastern Guangdong coast, Zhujiang River Delta and western Guangdong-Guangxi coast) along Chinese coast.
Key Input	Sea level change value and rising rate of all major tidal gauges along Chinese coast and the projection value of global sea level rise in the future given by IPCC.
Ease of Use	Require considerable knowledge on tidal and sea level analyses and prediction modeling technique.
Training Required	Requires little training for practical purposes that depend on user expertise.
Training Offered	No formal training currently offered.
Computer Requirements	Standard PC(Pentium or better)
Documentation	Zhang Jinwen, The prediction model of MSL change along the coast of China, 1997; Du Bilan, Liu Fakong and Zhang Jinwen, The sea level rise threatening China's coastal vulnerable zone and its prediction; Both above papers are issued in proceedings *The Impacts of Sea Level Rise on the Major Vulnerable Areas of the China's Coastal Zone and Relevant strategies.* 1997(In Chinese) Prediction model for the sea level change along China's coast, 1999, *China Climate Change Country Study*, Tsinghua Umiversity Press. (In English)
Applications	Used only in Chinese coastal zone for adaptation options to climate change and sea level rise.
Contacts for Tools, Documentation, and Technical Assistance	Prof. Du Bilan and Wang Fang, China Institute for Marine affairs, No.1 Fuxingmenwai Avenue 100860 Beijing, P.R China, Fax: (8610) 68030767
Cost	US$ 1000 from China Institute for Marine Affairs.
References	See documentation above.

Calculating method of submergible area due to sea level rise for weakly defended coasts

Description	This method will be used to calculate the submergible area along coastal region with weak tidal defense, which helps the user to evaluate initially the scope of submerged area and risk of losses. This method requires the tidal level values at each tidal gauge, the type of tides, the characteristics of topographic and isohypse distribution between tidal gauges, top high value of sea walls and the background tidal levels especially the highest water level in record which is considered for the coasts with storm surge.
Appropriate Use	This method can be used for Coastal analysis, specially the initial evaluation of coastal vulnerability.
Scope	At the low-lying vulnerable coastal area with the storm surge and having weak tidal defense
Key Output	The final product is the impact map of potentially submerged area with different background tidal level (Mean Spring high water level, Highest water level in record or one hundred-year high water level) and different scenarios of sea level rise in the future.
Key Input	Coastal topographic data base and Digital Elevation Model on the appropriate scale; observational tidal data series; type of tides for different coastal areas.
Ease of Use	Requires considerable knowledge on a range of techniques for topographic and oceanographic characteristics in coastal zone, and the GIS.
Training Required	The little training is required which depends on user expertise.
Training Offered	No formal training currently offered.
Computer Requirements	The computer hardware is: working station SUN and The software is: ARC/INFO and ARC/VIEW
Documentation	Du Bilan, Potential impacts of sea level rise on Chinese coastal major vulnerable zones, *The impacts of sea level rise on the major vulnerable areas of the China's coastal zone and relevant strategies,* China Ocean Press, 1997, p.10-16(In Chinese) Impact of climate change on sea level rise and adaptive strategies, *China Climate Change Country Study*, Tsinghua University Press, 1999, p.181-190.(In English)
Applications	Used for Zhujiang River Delta area (Natural impacts of sea level rise on the Zhujiang River Delta area, 1995), Changjiang River Delta area (Impacts of sea level rise on Changjiang River Delta and coastal area of Jiangsu and North Zhejiang and relevant strategy, 1997) and the Yellow River Delta area (Computation of flooded coastal area of Bohai Gulf and Laizhou Bay with different scenarios of sea level rise, 1997).
Contacts for Tools, Documentation, and Technical Assistance	The National Geomatics Center of China, China Institute for Marine Affairs and National Marine Data and Information Service jointly has developed this method. Contact with associate Research Professor Wang Fang, China Institute for Marine Affairs, No.1 Fuxingmenwai Avenue 100860, Beijing, P.R. CHINA, Fax: (8610)68030767.
Cost	No cost to obtain documentation.
References	See documentation above.
Other remarks	Owing to this method developed only for internal research use it should be improved in the future.

Runoff Evaluation System (RES)

Description	This Windows based software package is an advanced runoff and water resources analysis tool for different selected river basin in China, which is powerful to treat with observed data or simulated data under the impact of climate change. It is specially adapted to broad river basin runoff change problem. The user can project changes in water resources development, utility and pollution for selected catchments. Runoff Evaluation System includes evaporation models, hydrological runoff models, and river flow simulating models, decision support analysis models.
Appropriate Use	Water resources analysis under various hydrological conditions. So the system can help to evaluate water resources strategies for adaptation to climate change.
Scope	All locations, ground and surface water systems; national or site-specific.
Key Output	Water allocation and evaporation at selected nodes, flows in river reaches.
Key Input	Local climatic data, hydrological data (hourly or daily) covering decades of years and hydrology engineering in selected catchment .
Ease of Use	Relatively easy to use. Detailed analysis requires significant data.
Training Required	Requires extensive knowledge of the physical characteristics of water system.
Training Offered	
Computer Requirements	IBM-compatible PC, Windows 95 above; Database servers for Client/Server database SyBase.
Documentation	
Applications	The models have been used to analysis water resources in Yellow River.
Contacts for Tools, Documentation, and Technical Assistance	Water Resources Information Center (WRIC), Ministry of Water Resources (MWR) , P.R.China; Tel: 86-10-63202426
Cost	Varies, depending on data needs and resources required for developing a unique model
References	

Flood and Drought Risk Analysis System (FDRAS)

Description	Flood and Drought Risk Analysis System includes a series of river flood forecasting model, water balance model and Math-theoretical Analysis and statistics model. Designed to estimate the time-varying changes in the frequency of flood and drought and their socio-economic consequences across all sectors. Express these in return period and a risk assessment framework, taking uncertainty into account.
Appropriate Use	Estimation of the time-varying changes in the frequency of floods and droughts and their socio-economic consequences across all sectors. Express these in return period and a risk assessment framework, taking uncertainty into account.
Scope	Major rivers and river catchments; national or site-specific.
Key Output	Above analysis with the inclusion of risk uncertainty factors.
Key Input	Local climatic data, hydrological data (hourly or daily) covering decades of years and hydrology engineering in selected catchment .
Ease of Use	Relatively easy to use. Detailed analysis requires significant data.
Training Required	Requires extensive knowledge of the physical characteristics of water system.
Training Offered	
Computer Requirements	IBM-compatible PC, Windows 95 above, or WindowsNT 4.0 above; Database servers for Client/Server database .
Documentation	
Applications	River flood forecasting in Yangtze River, Nenjiang River, Taihu Lake, etc.
Contacts for Tools, Documentation, and Technical Assistance	Water Resources Information Center (WRIC), Ministry of Water Resources (MWR) , P.R.China; Tel: 86-10-63202426
Cost	Varies, depending on data needs and resources required for developing a unique model
References	

PAPER NO. 2: UNITED STATES OF AMERICA

UNITED STATES SUBMISSION ON TOOLS FOR CLIMATE CHANGE IMPACT AND ADAPTATION ASSESSMENT: A REVIEW OF DECISION-MAKING AND DECISION-SUPPORT TOOLS FOR EVALUATING ALTERNATIVE ADAPTATION STRATEGIES

I. Introduction

Adaptation refers to any adjustment that can respond to anticipated or actual consequences associated with climate change (IPCC, 1996). All nations must assess options and develop adaptation strategies to assist in mitigating adverse impacts and exploiting potential opportunities arising from climate change. Although various classifications of adaptations can be found in the climate change literature, the UNEP *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies* (1998) used the eight categories described by Burton et al. (1993):

- Bear losses.
- Share losses.
- Modify the threat.
- Prevent effects.
- Change use.
- Change location.
- Research.
- Educate, inform, and encourage behavioral change.

Some of the documented difficulties in developing and implementing adaptation strategies include:

- The locus for environmental decision-making is increasingly at the sub-national level, yet there are inadequate resources devoted to serving these decision-makers.
- The findings of past research have not been synthesized and integrated in such a way that they can be used to tailor approaches suitable for the array of actual decisions that must be made. For example, Moser (1998) found that global change and sea level rise-related information plays no role in the daily decision-making of coastal managers because the very task- and locality-specific information is not readily available.
- The tools available most often have been designed for use on big problems at a national level where time, information requirements, money, and trained practitioners are not the constraints they typically are in most sub-national decision situations.
- No guidelines are available to inform decision-makers of what processes work well under particular circumstances.
- An adequate decision-support infrastructure has not been constructed.
- Decision- makers are not trained to take advantage of the knowledge that does exist and do not have adequate opportunities to share what they learn with one another.

Some recent surveys of decision-makers in the United States (Wolfe et al., 1997; NOAA Coastal Services Center, 1998) revealed that critical needs regarding selecting strategies for environmental issues such as climate change included:

- Access, technological and financial, to a wide range of tools, such as databases and models;
- Assistance in determining how to use the sometimes overwhelming amount of existing information or new data and information generated through problem-specific analyses;
- Assistance in determining what information is needed to make an informed decision, and therefore, in determining what tools should be selected for use.

The *Compendium of Decision Tools to Evaluate Strategies for Adaptation to Climate Change* (Smith et al., 1999) addresses the first need. It provides an excellent overview of "specific evaluation tools that are best applied to examining specific adaptation options such as how to manage coasts to incorporate sea level rise or whether to modify water infrastructure." Thirty-two tools are organized by applicable sector, i.e., water, coastal, agricultural, and human health resources, and general tools applicable to multiple sectors. The authors' rightly note that the described in the report "should not be implemented in isolation, but rather in conjunction with a country's overall response to climate change."

The total set of decisions related to adaptation to climate change is vast. For the purposes of this review, tools to support decision-making have been organized into eight functional areas, which represent important inputs to the decision-making process:

- Identify the problem.
- Identify environmental values and determine goals.
- Characterize the environmental and socioeconomic setting.
- Integrate information.
- Identify options.
- Forecast.
- Assess, refine, and narrow options.
- Make the decision.
- Post-decision assessment.

Although these steps are discussed sequentially, it is important to keep in mind that the process of generating and evaluating alternatives is dynamic, evolving and interactive. The evaluation of alternatives may identify new strategies, which in turn are evaluated. Decision-makers at different organizational levels make different kinds of decisions, based on different kinds of information, using different kinds of tools. Thus, decision-making cannot be constrained to deterministic decision-making models.

The examples of tools provided in the discussion of each of these areas represent only a subset of the multitude of methods, both "hard" and "soft," available to the decision-maker. Inclusion of a specific technique or software is intended to be only representative and should not be viewed as an endorsement.

II. The Problem

One of the most fundamental issues facing decision-makers is whether to implement responses to climate change today or defer preparation until we understand the impacts better and they are more near term (Titus, 1990):

> "The need to respond today depends on (1) the likelihood of global warming; (2) the magnitude of the impacts; and (3) the potential for anticipatory measures to reduce adverse impacts if sea level rises or climate changes as expected, without imposing substantial costs if the changes do not unfold. Although the literature on the first two factors is extensive, the latter issue has rarely been mentioned. As a result, some people assume that it would be unwise to prepare for global warming until its eventuality and consequences are firmly established. "

In evaluating potential responses to climate change, Titus (1990) list a number of criteria that decision-makers will have to consider:

- Economic Efficiency: Will the initiative yield benefits substantially greater than if the resources were applied elsewhere?
- Flexibility: Is the strategy reasonable for the entire range of possible changes in temperatures, precipitation, and sea level?
- Urgency: Would the strategy be successful if implementation were delayed ten or twenty years?
- Low Cost: Does the strategy require minimal resources?
- Equity: Does the strategy unfairly benefit some at the expense of other regions, generations, or economic classes?
- Institutional feasibility: Is the strategy acceptable to the public? Can it be implemented with existing institutions under existing laws?
- Unique or Critical Resources: Would the strategy decrease the risk of losing unique environmental or cultural resources?
- Health and Safety: Would the proposed strategy increase or decrease the risk of disease or injury?
- Consistency: Does the policy support other national state, community, or private goals?
- Private v. Public Sector: Does the strategy minimize governmental interference with decisions best made by the private sector?

Another important problem for the decision-maker is deciding on the proper suite of actions to take as part of an overall strategy to address climate change. As Crosson and Rosenberg (1991) state:

> "Adaptation and mitigation are sometimes treated as mutually exclusive approaches to dealing with global warming, but it is now acknowledged that they can be pursued jointly and that there are tradeoffs between them. A critical policy issue is the determination of which mix of adaptation and mitigation measures will maximize the benefits of efforts to reckon with

> climate change. Unfortunately, much less is known about how to adapt to that change than how to mitigate it. Despite this fact, the developed and developing countries have a mutual interest in devising adaptive responses…"

III. Tools to Identify Environmental Values

Tools for identifying environmental values include methods based on economic markets, methods based on ecological relationships, preference surveys, and small-group elicitation. Contexts in which these tools are employed include communicating environmental choices to the public, defining concerns in a common language and format, and developing project alternatives using information about environmental values

A. Economic Market-based Tools

Economics can play a role first in helping people to understand the benefits and costs of reducing the impacts of climate change by assessing people's tradeoffs between reduced threats and other benefits. Such a comparison is important because tradeoffs will need to be made in the allocation of resources to meet climate change concerns versus meeting other needs. Economic analysis offers tools and a framework to investigate these tradeoffs.

Economic valuation can be defined as the attempt to assign quantitative values to the goods and services provided by environmental resources, whether or not market prices are available to assist us (Barbier et al., 1996). Economic markets reveal what matters to individuals based on what they are willing to buy and sell. The prices we attach to environmental goods, whether in a real or hypothetical situation, can provide information about our environmental values. In the absence of ownership and efficient pricing, special techniques are needed to place consumers' preferences for environmental goods and services on the common ground with demand for more conventional commodities (Navrud and Pruckner). Market-based tools help identify values that may or may not be directly expressed in dollar terms. Typical costing methods seek to identify one or more of the following:

- Restoration/replacement costs, which identify costs needed to remedy or compensate for an environmental disruption.
- Travel costs, which identify values based on the number of people who visit a site and the travel costs they incur in getting there;
- Hedonic (characteristics-based) pricing, which seeks to capture unpriced values in the prices of marketed goods (for example, by comparing the market price of land with and without a scenic view);
- Damage schedules, which provide scaled rankings of the relative importance of environmental harms.

Valuation of environmental and health impacts using these nonmarket valuation methods have evolved from being mainly a US activity in the 1960s and 70s to become important tools applied at an increasing rate in other developed and developing countries throughout the world (Navrud and Pruckner). Evidence of this development include the preparation of Environmental Valuation Field Guides by the Organization for Economic Cooperation and Development (OECD) in cooperation with the World Bank, the United Nations

Environmental Programs (UNEP) Framework Action Program on Environment and Economics, UNEP's guidelines on environmental valuation in their program of country studies of biodiversity, and similar efforts by the Asian Development Bank, the United Nations Development Program (UNDP), and the World Health Organization (WHO). In addition, there is a large body of literature on the application of these methods for resource evaluation, including site-specific studies (Carson et al., 1994; Dorfman et al, 1996; Freeman, 1998; McConnell, 1990; Smith 1990; 1996) and guidelines for the valuation of specific habitat types, such as wetlands (Barbier et al., 1997).

Another promising area for economic analysis is in contributing to the design and effectiveness of health and environmental surveillance and monitoring systems (Krupnick, 1998). For example, the Peruvian government started predicting rainfall regimes related to El Nino disturbances as early as 1983. Farmers were then assisted in deciding whether to plant rice, which thrives in wet weather, or cotton, which tolerates drier weather. Other countries have since used El Nino predictions to help make agricultural decisions. And major efforts have been made to bolster ocean surveillance for El Nino events, as well as to plan the development of integrated health and environmental monitoring systems to help understand and predict the linkages between climate change, weather, ecology, and health. In economics, a "value of information" (VOI) analysis is used to help identify the potential gains from such information systems and the associated systems for human responses to better information (Krupnick, 1998). The benefits of better information depend on the type of information provided, to whom it is provided, how it is disseminated, the available actions to take (and their costs) conditional on receiving the information, the risks and consequences of the predictions being wrong, and an estimate of the baseline – what choices would have been made in the absence of the better information. These benefits can be compared to the costs to help determine which investments in early warning *and* response systems are most justified.

B. Ecological Relationships

Ecological relationships focus on modeling ecological system functions--such as environmental health, integrity, resilience, and carrying capacity--to clarify the link between these functions and human welfare.

Typical tools include:

- Integrated-assessment frameworks.
- Probabilistic analysis.

1. Integrated Assessments

Integrated assessment has emerged as an approach to guide scientific research on global climate change and to help formulate new and more effective policies in response to global climate change. Integrated assessment provides a consistent framework for combining knowledge from a wide range of disciplines (CIESIN, 1995). The main goal is to provide policy makers with insights that would not be possible through isolated studies of various component pieces of the problem. Integrated assessment provides a basis for comparing alternative policy choices, allows policy issues to frame the direction of scientific research and development, involves existing scientific knowledge, accommodates new knowledge as it becomes available, and provides a bridge between science and policy. It therefore provides a natural platform for the analysis of complex environmental problems such as climate change.

The Common Methodology developed under the IPCC reflects trends toward more regional-scale assessment (Long and Iles, 1997). This methodology has played an important role in the evolution of the sea-level rise impact sector. The Common Methodology contains seven steps for assessing the ability of nations to cope with the consequences of sea-level rise. It examines, through case studies, the susceptibility of coastal zones to physical changes, the impacts of these physical changes on socio-economic and ecological systems, and the degree of risk that populations, social systems, and property face. The Common Methodology recognizes that there can be multiple vulnerabilities (physical, ecological, and socio-economic), and encourages much greater desegregation of data and assessment than previously practiced. It encourages highly site-specific assessment that is sensitive to prevailing local conditions. Further, the Common Methodology requires a combination of many disciplinary areas, especially social science and policy management, and can be used to cross the boundaries between science, policy, and politics by generating specific recommendations regarding infrastructure and other response strategies.

Traditional approaches towards integration largely relied on qualitative linkages. Recently, there has been an increased interest in formalizing these linkages through mathematical models (CIESIN, 1995). These Integrated Assessment Models (IAMs) make it easier to insure consistency and can also help decision-makers "simulate" possible implications of planned policies. Several developers of computer software are working on systems to facilitate the development and management of models and their ease of use by non-experts. These tools promise to increase the ease, flexibility, and transparency with which component activities of assessment, such as building and revising models, describing and propagating uncertainty, and analyzing sensitivity, can be done. Increasing the accessibility, ease, and communicability of these tasks can change the fundamental organization of assessment activities by making them accessible to a wider community with less specialized technical training and making them easier and faster to do and to discuss.

There are several comprehensive reviews of integrated assessment and integrated assessment models (CIESIN, 1995; Dowlatabadi, 1995; Rotmans et al., 1996; Weyant et al. 1996). Several examples for illustrative purposes are:

- The IMAGE models, which are global, dynamic simulation models based on the systems-dynamics approach to modeling, were developed by RIVM in the Netherlands. The first impacts modules concentrated on sea-level rise and coastal defense, and allowed calculation of optimal policy response in the form of optimal time-paths for dike raising and dune strengthening.
- ESCAPE (the Evaluation of Strategies to address Climate change by Adapting to and Preventing Emissions) allows a user to explore the implications of different climate-related policies both for global-mean climate and for indicators of the economic and environmental impact of climate change within Europe. The model provides an assessment of the scientific uncertainties surrounding the prediction of future climate change and its impacts. A paper summarizing the ESCAPE framework, including some

illustrations of analyses undertaken with this model, has been prepared by Rotmans et al (1994a).

- The TARGETS model (Tool to Assess Regional and Global Environmental and health Targets for Sustainability) seeks to study not just climate change, but broad issues of global change and sustainable development (Rotmans et al, 1994b). TARGETS include five interlinked "horizontal" modules representing population and health, energy and economics, biophysics, land and soils, and water. Cutting across each horizontal module will be a consistent framework representing dynamics within four "vertical" modules that describe the state and dynamics of the system, the pressures on it, the resultant impacts, and the range of policy responses.
- The Policy Evaluation Framework (PEF), developed by the U.S. Environmental Protection Agency and Decision Focus Incorporated, is a decision analysis tool that enables decision-makers to continuously formulate policies that take into account the existing uncertainties, and to refine policies as new scientific information is developed. It is designed to provide a framework for integrating and evaluating the best available information from the diverse elements that influence climate policy. PEF encourages exploration of the policy implications of alternative technological, economic, physical, and biological assumptions and scenarios and integrates deterministic parametric models of physical, biological, and economic systems with a flexible decision tree system. The deterministic models represent greenhouse gas emissions, atmospheric accumulation of these gases, global and regional climate changes, ecosystem impacts, economic impacts, and mitigation and adaptation options. The decision tree system captures the key scientific and economic uncertainties, and reflects the wide range of possible outcomes of alternative policy actions.

2. Probabilistic Analysis

Probabilistic analysis, which provides insights about either event-based uncertainty (particularly, a lack of data about ecological relationships), or knowledge-based uncertainty (particularly, a lack of knowledge or agreement among experts regarding ecological impacts of an action).

An excellent discussion of the use of and need for probabilistic projections for decisions on appropriate responses to climate change is found in Titus and Narayanan (1996). In the case of sea level rise, the authors point out that decision-makers must compare the costs of various adaptation measures to the costs of taking no action. Before deciding on an appropriate course of action, decision-makers must convert a scenario into a probability estimate of the magnitude of sea level rise. Results from general circulation models alone do not provide the most likely scenario or the full range of possible outcomes. Therefore, climate change impact assessments should employ probability-based projections of regional climate change (see discussion below of probabilistic risk assessment).

C. Expressed Preferences Surveys

Expressed preferences surveys ask people their opinions and beliefs and assume their answers indicate their values. Examples of typical tools include:

- Attitudinal surveys, which explore people's orientations to the world around them (for example, how they balance economic, social, and personal desires against their desire for environmental protection);
- Opinion surveys, which are used to discern public views about particular environmental policies or proposed actions and to test their acceptability with the public;
- Contingent-valuation techniques, which are used to present a hypothetical market for an unpriced environmental item to people so that they can determine the maximum price they would pay either to buy the item or to avoid the item;
- Constructed preferences, which use multiple scales to identify and compare environmental values because the effects of environmental policy actions cannot always be represented in monetary terms;
- Conjoint analysis, which attempts to build an understanding of people's environmental values by asking them to make a series of structured, paired comparisons;
- Image-based techniques, which examine positive and negative images that are associated with various policy options and their possible consequences.
- Public-value surveys and value-integration surveys, which help elicit values for the individual characteristics of an environmental resource and combine these characteristics as part of the development, ranking, or rating of a set of proposed alternatives;
- Decision-pathway surveys, which consist of a set of linked questions that are used to draw out people's reasoning by allowing them to select a response pathway that represents their thinking about an environmental policy;
- Narratives (affective expressions), which uses in-depth individual interviews to explore emotional responses to a real or imagined scenario and examines explanations and justifications for feelings that are expressed;
- Referenda, either binding or nonbinding, which can be used to elicit voters expressions of support or opposition to proposed policies.

The AGORA-COAST technique, developed under the EC funded study VALCOAST (**VAL**ue **CO**nflict **AS**sessment **T**echniques), is a non-monetary valuation, conflict management and decision support technique for determining stakeholders' priorities for different criteria and applying these criteria for selecting among alternative CZM strategies (Davos et al., 1997).

D. Small-group Elicitations

Small-group elicitations are used to identify environmental values and to further define and understand a participant's interest in an issue. Examples of typical tools include:

- Focus groups, in which individuals participate in a structured group session in which their key concerns and expectations about an issue are elicited;
- Advisory committees;
- Multiattribute elicitation, which helps select a favored policy alternative by structuring participants' objectives and trade-offs.

IV. Characterizing the Environmental and Socioeconomic Setting

A basic building block for environmental decisions is good scientific, social, and economic information to which decision- makers have ready access, and on which they can and will rely.
The need for global data falls into two basic categories: 1) requirements for data sets to solve global scale problems, and 2) requirements for local or regional data sets on a world-wide basis (GCOS, 1997). Climate change, its detection, prediction and understanding its impacts clearly requires global data sets. Local to regional data sets collected world-wide are needed to determine the consequences of such change upon people and their well-being and management responses local to regional problems that are so pervasive that they occur around the globe.

A. Integrated Environmental Observing Systems

Some argue that global environmental data are limited while others believe that climate change researchers possess a profusion of data. Taken further, it is also argued that despite this wealth of data, there is very little information useful for decision-making. The need has been identified to capture the non-scientific knowledge base and present the information directly to decision-makers in a format which is understandable and which will contribute to the decisions. An additional barrier is data accessibility. Once the problems of data access are overcome it is often found that the databases are incompatible and inconsistent which hinder the decision-making process. One approach to overcome these impediments is the creation of integrated, "end-to-end" observing systems.

The understanding of the challenges presented by global change lies in the coupling of a set of long-term observations over a range of temporal and spatial scales with process studies and models. The Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS) and the Global Ocean Observing System (GOOS) were created by the World Meteorological Organization (WMO), the United Nations Environment Program (UNEP), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council of Scientific Unions (ICSU) to provide the required observations. These global networks are a system of distributed data bases, which themselves consist of many levels of monitoring programs

The ideal integrated environmental observing system consist of three components: 1) an observing subsystem of integrated measurement programs that are multi-disciplinary (synoptic measurement of key physical, chemical and biological properties), multi-dimensional (e.g., integration of remote and *in situ* measurement made on different time and space scales), and multi-scale (local-regional-global in scope); 2) a communications network; and 3) a system of integrated data management that enables the rapid exploitation of data sets from disparate sources to serve the needs of a variety of different user groups.

1. Observation Systems

The observing subsystem includes:
- Diverse sensors, measurements (physical, chemical, biological, meteorological, multi-disciplinary), and scales;
- Platforms (satellites, aircraft, ships, moorings, drifters);
- Real- and near-real time measurements v. delayed-mode.

Measuring devises may range from simple tide or rainfall gauges to global positioning satellites for environmental characterization.

2. Communications

The communications network links data providers and users, observations, subsystems, and data repositories. The optimum network must:
- allow numerous, remotely located users to interact with each other while navigating datasets;
- provide a framework to give a wide cross-section of users access to content;
- possess an ability to communicate in real-time;
- include intelligent network agents to automatically inform users about certain events, such as new data for a region of interest;
- provide navigation schemes and capability to browse large quantities of data distributed over a wide-area network.

Some examples of international, national, regional, and local environmental communications networks include:
- INFOTERRA, which is the global environmental information exchange network of the United Nations Environment Program.
- The USGS Energy Resources Program, which provides an Internet solution to deliver digital energy resources information to users' desktops.
- The California Ocean and Coastal Ocean Environmental Access Network, which is a comprehensive online ocean resource information system;

3. Data Management

The data management subsystem, includes:
- spatial and non-spatial data and data mining tools for storing, indexing, and retrieving data;
- multi-resolution data representations to allow users to navigate rapidly from regional vantage points down to a specific habitat;
- standards for data and metadata and information exchange protocols;
- intuitive mechanisms for querying and manipulating data.

There are great number of climate change related "data services", where some combination of data, access software, database/navigation functionality, visualization tools, and support are provided. A multitude of data formats and visualization tools are employed, and the services address both archival as well as real-time data. Most, if not all, of the data service providers offer WWW access to their data holdings, as well as peripheral software and tools. Several international, national, and regional

Scientific utilization of hydrographic ocean data has been greatly facilitated by the use of EPIC, which is a scientist's desktop system for access, display and analysis of ocean observational data sets. EPIC was developed at the US National Oceanographic and Atmospheric Administration's (NOAA) Pacific Marine Environmental Laboratory to manage the large numbers of hydrographic and time series oceanographic *in-situ* data sets collected as part of NOAA climate study programs, such as EPOCS and TOGA in earlier years, WOCE and CLIVAR and others more recently. The system provides climate researchers with sophisticated data management, visualization and analysis procedures for oceanic hydrographic data, in support of the cross cutting science efforts required for assessment and prediction of annual and decadal climate variations and changes. The EPIC system is freely available by anonymous ftp from ftp.pmel.noaa.gov (anonymous/epic) and the WorldWide Web/Mosaic at http://www.pmel.noaa.gov/epic/home.html.

Housed at the California Institute of Technology (Caltech), the Laboratory for Global Environmental Science Information (LaGESI) was launched in conjunction with NASA's Jet Propulsion Laboratory "to increase the use of Earth science data sets to improve our understanding of global and regional environmental science issues." The LaGESI Website (http://www.lagesi.caltech.edu) offers access to a large collection of earth science data, simulations of earth science visualization software including WebWinds (http://webwinds.jpl.nasa.gov), earth science education activities and modules, and support information (alerts and technical assistance). Online data vary in accessibility, scope, and detail, but include atmosphere (AVIRIS, ATMOS, GENESIS, GCMD), land (AIRSAR, AVIRIS, MASTER, GCMD), and ocean data (AIRSAR, AIRSEA, AVIRIS, MASTRER, NSCAT, PO-DAAC, TOPEX, and GCMD). The WebWinds software provides for exploratory visualization and analysis of many different data sets and allows users to manipulate the data directly at their desktop computers.

The THETIS system is a digital library of collections of multimedia information, scientific models, and visualization tools needed to locate and use for coastal zone management for the Mediterranean Region of Europe (Houstis, et al. 1997). It addresses the requirement of scientists, engineers and decision-makers to access, process and subsequently visualize data collected and stored in different formats and held at different locations. The user interface is based on a Web browser, and includes a GIS interface. When a user selects a region of a map through the WWW browser, the coordinates of the region are used to index the appropriate information about the region. The user can zoom into a region of a map (or image) and query for various properties about the region or perform some operations on-line such as retrieving and comparing time-series data on beach levels to support decisions regarding adaptation strategies to sea level rise.

The Real-time Environmental Information Network and Analysis System (REINAS) is a distributed measurement-gathering environment built around one or more relational database systems and supporting both real-time and retrospective regional scale environmental science. REINAS was developed at the University of California at Santa Cruz, in cooperation with meteorological and oceanographic scientists from the Naval Postgraduate School (NPS) and Monterey Bay Aquarium Research Institute (MBARI), Continuous real-time data is acquired from dispersed sensors and input to a logically integrated but physically distributed database. An integrated problem-solving environment supports visualization and modeling by users requiring insight into historical, current, and predicted oceanographic and meteorological conditions.

B. Socioeconomic Information

The primary purpose of tools to gather social, economic, and political information--secondary/archival techniques, primary/fieldwork techniques, and gaps-and-blinders techniques--is to aid understanding of people and the ways they will affect and be affected by a prospective environmental decision. These tools, developed within the social sciences over many decades, provide many avenues for information gathering.

In the environmental decision-making arena, if we can recognize the social and economic impacts a decision will have, we may be able to find the extent to which the impacts can be reversed or mitigated. These techniques also help to systematically incorporate the views of sometimes overlooked segments of the population into the decision process. In addition, the results from these tools may help us to understand both the distribution and the severity of the impacts a decision has on a community.

Although these techniques offer many advantages, they also have their pitfalls. In some cases, the information you need will take time and effort to find. These research methods, however, often produce information about a decision that you would not find through traditional methods. When obtaining information from participants, questions need to be carefully structured so that you will get the information you need.

V. Data Conversion and Information

The questions arise as to what kind of information sub-national policy- and decision-makers need in order "to factor in" climate changes, such as sea level rise, into their policies and management activities? In what form, from whom, and when do they need it? Are these needs known to, and can information producers or providers meet them? What is "useful" and credible information? What are the factors and processes -- both inherent in the information itself and in the institutional set-up through which information exchange takes place -- that bring about "effective" information use? In other words, how can the plethora of scientific global change information produced internationally and nationally be made more useful to those who ultimately will have to decide on and implement pragmatic responses to a changing environment at the state, regional, and local levels (Moser, 1998)?

A data conversion and information product development and delivery mechanism must exist to bring the vast array of scientific, monitoring, organizational, and process information together in a system accessible to most decision-makers. However, availability will not automatically result in increased information use for decision-making. For example, INFOTERRA operates through a system of government-designated national focal points. The primary function of each focal point is to provide a wide range of environmental information products and services including environmental bibliographies; directories of sources of information; query-response services; environmental awareness leaflets; and access to Internet services. But as Potter (1995) states: "The Infoterra Focal Points cannot significantly increase the use of environmental information in either environmental decision-making, or the wider arena of local development planning." because they "generally are not well sited in the structure of government to be able to 'insert' new information in the decision processes" and they "have no training or tools to convert the environmental information to which they have immediate access into information products…which are required to support decision-making."

Information technology, and in particular, the integration of data base management systems, GIS, remote sensing and image processing, simulation and multi-criteria optimization models, expert systems, and computer graphics provide some of the tools for effective decision support in natural resources management Fedra, 1994). Tools for integrating spatial information – geographic information systems (GIS), spatial decision-support systems, and spatial models – have become commonplace in environmental decision-making at all levels. GIS combines a base map with attribute data. Spatial decision support systems (SDSS) combine GIS technologies with mathematical models to simulate results of various actions and allows users to consider and evaluate a series of "what-if" questions about management decisions. These systems also allow users to track performance measures of alternative approaches to a management problem. Spatial models combine spatial information with simulation models to predict changes over time and space.

A. Decision Support Systems

Information-integrating or decision support tools show relationships among different types of data and are typically used to answer a variety of questions about the impacts of alternative scenarios. Sol (1983) defined decision support as the: "development of approaches for applying information systems technology to increase the effectiveness of decision makers in situations where the computer can support and enhance human judgment in the performance of tasks that have elements which cannot be specified in advance." Decision support systems were developed in response to the advancements in computing technology which made it possible to place computing power in the hands of decision-makers (Konsynski et al., 1992; Er, 1988; Keen, 1987). They are analytical tools, which can be used to assist the decision-maker in assessing the inter-relationships and potential effects of a policy or decision. Information integration must include the ability to scale information without distorting the technical content and be able to handle temporal information and support spatial information throughout the analysis and decision-making process (van Voris et al, 1993). An example is SYLVATICA, which is an integrated framework for forest landscape simulation; it used a variety of consultation systems to allow the user to visualize the effects of silviculture or other resource management strategies, natural or anthropogenic disturbance, or global climate change over long term horizons (Host et al, 1992).

B. Geographic Information Systems

GIS is an especially valuable technology for capturing and displaying large amounts of detailed information essential for informed development planning. GIS displays are also powerful public education tools, facilitating an understanding of alternative development costs and benefits and aiding the process of public decision making. AN excellent overview of GIS applications to managing spatial information for coastal zone management is provided in Canessa (1998). Several recent examples of GIS applications, which have relevance to assisting decision-makers in determining strategies for adaptation to climate change, include:

- The Australian Coastal Atlas Project, which is a GIS disseminating coastal information across the Internet.
- The U.S. Department of Agriculture is developing of a "geographic information server" capability to support spatial data serving to the agricultural community.

C. Spatial Decision Support Systems (SDSS)

Spatial decision support systems (SDSS) are the spatial analogue of decision support systems (DSS) developed in operational research and management science for business problems.. Similar analogies can be made with respect to GIS in the development of SDSS (van der Muellen, 1992; Fedra and Reitsma, 1990). As with DSS, SDSS were developed for those semi- or unstructured decision problems for which there is no straightforward means of solution.

A concise and consistent definition of SDSS is not evident from the literature. In general, SDSS are computer systems which combine a database management system, spatial and non-spatial analytical models, and graphical and tabular reporting integrated with human-expert knowledge within a decision-making framework accessed by a user-friendly interface to provide alternative solutions to a decision problem (Carver, 1991; Densham, 1991; Honey et al. 1991). Although many of these components can be said to be found in GIS, SDSS are differentiated from GIS by the addition of advanced spatial analysis capabilities (e.g. MCA), the expertise of the decision-makers and a suitable user interface (Carver, 1991). SDSS emphasize the iterative and interactive generation and evaluation of alternatives rather than traditional optimizing choice processes (Densham and Armstrong, 1987). Some representative examples include:

- TERRA-Vision is a decision support system for risk assessment of terrestrial environmental resources which combines scientific analysis and the decision making process in a DSS. The goal of the system is to provide a scientifically based method for establishing the potential effects of a policy of decision. The system combined graphical and mapping capabilities provided by a GIS with a 3D visualization system with temporal and real time capabilities (van Voris et al, 1993) along with models representing environmental, atmospheric, economic and political criteria.

- CORA was developed to assist the staff of NOAA's Biogeography Program and other groups in integrating and analyzing large, diverse coastal resource data sets, and in generating maps and summary reports on the distribution, abundance and habitat of coastal fish and invertebrates. CORA users can address a wide range of questions on the relationships between species distributions and environmental parameters. CORA's map and tabular products primarily species distribution and abundance and related environmental parameters, and can be used in environmental impact statements, species and habitat assessments, restoration plans, and research.

- Habitat suitability modeling is a map development technique used to estimate the habitat suitability of an area for a species. HSM uses theoretical or empirical models to produce maps of habitat suitability for selected fish and invertebrate species, or to predict the effects of environmental change. HSM is a custom extension of ESRI's ArcView GIS Spatial Analyst.

VI. Assessing Options

Tools for assessing options assist users to develop alternative strategies, compare elements of different options, understand trade-offs between conflicting objectives, and choose the most effective alternative to meet a specific objective (Merkhofer, 1998.) Common tools are 1) probabilistic risk assessment; 2) cost-benefit analysis; and 3) decision-analysis.

Probabilistic risk assessment, which describes and measures risk, allows the user to evaluate the type, nature, and magnitude of possible adverse environmental consequences. Phases of probabilistic risk assessment- release assessment, exposure assessment, consequence assessment, and risk estimation. Examples are:

- Four databases have been developed to help identify coastal areas at risk to inundation and increased erosion hazards in the United States (Gornitz and White, 1992, 1994a,b). These databases have been used to study and assess both the erosion and permanent or episodic inundation potential of storm-induced or climate change increases in sea level andwere designed to be used by regional planners for the identification of high-risk areas for more detailed study. Areas at risk were identified using a "coastal vulnerability index," which weighted 7 to 13 variables according to the perceived importance of each in determining the relative vulnerability of an area to sea-level rise.
- The Community Vulnerability Assessment Tool, developed by the NOAA Coastal Services Center is an informational aid designed to assist communities in their efforts to reduce hazard vulnerability. This CD-ROM includes a newly developed methodology for conducting a community-wide vulnerability assessment. The general methodology is included as a tutorial that steps the user through a process of analyzing physical, social, economic, and environmental vulnerability at the community level.

Cost-benefit analysis compares alternatives based on their monetized advantages and disadvantages. Phases of cost-benefit analysis include:

- estimating costs of an environmental decision, using tools such as econometric and engineering models or cost-effectiveness analysis;
- estimating impacts, using tools such as socioeconomic impact assessment and integrated impact assessment;

- valuing impacts (an example tool is contingent valuation and ranking);

- computing net benefit, which assigns a value to a decision, taking into account benefits and costs over time, the time period for evaluating the decision, and a discount rate. Example tools are sensitivity analyses and calculation of net present value.

Decision analysis allows a decision-maker to identify alternatives, estimate outcomes, assign probabilities, and establish what can be done. Values are assigned to possible decision outcomes, which are then ranked, and preferences for alternatives involving uncertainty are measured. The preferable alternative is the one receiving the highest rank, according to the analysis. Phases of decision analysis include decision framing, deterministic analysis, probabilistic analysis, and evaluation.

Decision framing helps define the problem by organizing objectives in a hierarchy. Example tools are performance measures, which measure the consequences of each alternative, and influence diagrams. Deterministic analysis involves the use of consequence models, such as multiattribute utility analysis to predict the consequences of various alternative actions, and valuation models to evaluate these consequences. Probabilistic analyses are developed for uncertainties that may have a large impact on one or more alternatives or cause the preferred alternatives to change. An example tool is a decision tree, which consists of decision nodes showing available alternatives and chance nodes, which indicate possible outcomes to key uncertainties.

VII. Forecasting

Forecasting tools predict trends as well as the consequences of alternative decisions. These tools may be categorized as judgmental methods, extrapolation, econometric and simulation models, and combined forecasts (Armstrong, 1998).

Judgmental methods involve forecasts made by experts based on their experience and judgement. Example methods include:

- analogies;
- Delphi techniques, which involve panels of experts and independent, anonymous forecasts.

An example of this approach is provided in the study by Titus and Narayanan (1996) The authors noted that coastal decision makers often need a "bottom-line" answer to questions such as the necessary height of a seawall. In their effort to calculate a single probability distribution of future sea level rise, the authors first specified probability distributions for each parameter of their models and then solicited subjective assessments of these values from a group of experts. They gave equal weight to all of the reveiwers' assessments to derive a single probability distribution.

- expert's intention and expectation surveys, which are sent to decision makers to determine what actions they would take in a given situation;
- role-playing.

Extrapolation involves making statistical projections using historical trends, assuming that recent trends will continue (Titus and Narayanan; 1995).

Combining forecasts involves choosing different methods to make forecasts of the same event or series of events, and then combining the results. These are especially useful when uncertainty exists about which method is most likely to produce the most accurate forecast. Examples include:

- the SAFE project, which includes physical and numerical models to predict the medium and long-term performance of beach nourishment schemes;
- MIT Integrated Framework, which includes an economic model, a coupled atmospheric model, and natural ecosystems models;
- Asian-Pacific Integrated Model (AIM);
- North Carolina State University (NCSU) Coastal Marine Environment Prediction System (CMEPS), which contains a suite of interactively linked atmospheric and oceanic model components that provide a coastal and inland waterway surge model combining wind, waves and currents, that not only predicts general surge effects but also event-related inland flooding.

VIII. CONCLUSION

What, then, is needed to develop a sensible strategy and select technological options for adapting to future changes in climate?

Crossen and Rosenberg (1991) suggested:

- "First, we must gain a better understanding of the sensitivity and vulnerability of specific regions, industries, ecosystems, and societies to the normal range of climatic variability, and what can be done to diminish its adverse impacts."
- "Second, research establishments should be working to develop better responses to climate variability."
- "Third, as knowledge of the dynamics of climate change improves or signs of change are perceived, or both, scientific and engineering should be assigned to the development of the specific adaptations needed."

Titus (1991) suggests that decision-makers "first concentrate on the "easy" solutions, that is, those that are low cost; reasonable for the entire range of likely changes in climate; institutionally feasible; urgent; and equitable." For instance, a low-lying coastal area is likely to be flooded, destroying wetlands unless they migrate landward, and destroying towns unless they are protected. A town must first decide fundamentally whether or not to hold back the sea or retreat. If it intends to hold back the sea, then it must choose between elevating the land and structures, or erecting dikes and other protective works. If it intends to retreat, then a variety of land-use planning options may be appropriate, including rolling easements, compensated buyouts of vulnerable property, and in the case of vulnerable areas that might be developed, density restrictions." As this review describes, there are an immense number of sophisticated tools that might contribute to formulating a policy, but in some cases, a sophisticated study can waste time and resources that might be better spent actually implementing a solution whose identification does not require all the sophisticated data (Titus, personal communication).

Feenstra (1996) argues that "The urgency and importance of adaptation to climate change in developing countries makes it better to start studying it without waiting until the problems have been solved, even partially. Adaptation studies do not need to be directly linked to in-depth impact assessments." He suggests that this work can be conducted by:

- determining how vulnerable and important sectors in a country are coping with present climate variability, and how its adverse effects, now or in the past, could have been avoided or decreased
- Conducting specific in-country research into the four generic categories of anticipatory adaptation presented in the report of the Science and Technology Panel of the Global Environment Facility (GEF), *Planning for Adaptation to Climate Change*:
  - Increasing the robustness of infrastructural design and long-term investments.
  - Increasing the flexibility of vulnerable managed systems.
  - Enhancing the adaptability of vulnerable natural systems.
  - Reversing trends that increase vulnerability.

Important observations from this review might include:

- The process of generating and evaluating alternatives for adaptation to climate change is dynamic, evolving and interactive. Decision-makers at different organizational levels make different kinds of decisions, based on different kinds of information, using different kinds of tools. Thus, decision-making cannot be constrained to deterministic decision-making models.
- The vast amount of scientific global change information produced internationally and nationally must be made useful to those who ultimately will have to decide on and implement pragmatic responses to a changing environment at the state, regional, and local levels.
- New Internet-based mechanisms for data conversion and information product development and delivery mechanism are being developed to bring scientific, monitoring, organizational, and process information together in a system accessible to most decision-makers. However, availability will not automatically result in increased information use for decision-making.
- The transfer of new adaptation technologies and tools to select the most appropriate options must be accompanied by sustained capacity-building activities and networks.

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