

# **The Mozambique-Netherlands Capacity Building Project on Climate Change**

**Consultancy on the Training of the Task Force on the Assessment of Vulnerability (Impacts & Adaptation) of the economy of Mozambique to Climate Change**

## **Consultancy Report**

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## **1: THE TERMS OF REFERENCE (TOR) OF THE CONSULTANCY**

The International Consultant was recruited to provide services to the Mozambique - Netherlands Climate Assistance Programmer (NCAP). These services include:

- (a) Identification of data and information required for the training and development of the Vulnerability (Impacts and Adaptation) Report as a component of the Initial National Communication of Mozambique;**
- (b) Provision of the documentation and software on to assist the Team on the assessment of vulnerability of the various sectors of the economy;**
- (c) Training of the Task Team on the execution of the various models and tools to be used in the assessments of vulnerability and adaptation to climate change;**
- (d) Development of recommendations to improve the management of the Vulnerability development and reporting process and the National Communications Project as a whole; and**
- (e) Writing and submission of a Consultancy/Workshop Report.**

## **2: IDENTIFICATION OF DATA AND INFORMATION:**

The International Consultant provided a list of data and information (see box below) that will be required by the Task Team in the vulnerability and adaptation training workshop. The Consultant stressed the need to collect all or most of the data and information for use during the training, particularly for execution of the scenario development and biophysical models. Status of this data collection was assessed with the Team on the first day of the Training/Consultancy and is reported under the appropriate day of the Workshop Report.

## **DATA REQUIRED FOR VULNERABILITY AND ADAPTATION ASSESSMENT:**

### **A: DATA REQUIRED FOR THE DEVELOPMENT OF BASELINE AND CLIMATE CHANGE SCENARIOS**

1. Temperature
  - (a) Mean monthly temperature
  - (b) Mean annual temperature
  - (c) Mean monthly maximum temperature
  - (d) Mean annual maximum temperature
  - (e) Mean monthly minimum temperature
  - (f) Mean annual minimum temperature
  - (g) Soil and Earth Temperatures (surface, 5cm, 10cm, 20cm, 30cm, 40cm, 50cm, 1foot, and 4ft)
2. **Rainfall**
  - (a) Daily rainfall for all stations
  - (b) Average monthly rainfall
  - (c) Average annual rainfall
3. **Solar Radiation**
  - (d) Daily solar radiation for all stations
  - (e) Average monthly solar radiation
  - (f) Average annual solar radiation

### **B: DATA REQUIREMENTS FOR THE AGRICULTURE SECTOR**

1. Soil classification for each site (e.g. shallow, medium, or deep silty clay) silt loam, sandy loam, or sand).
2. A minimum of 30 years of daily weather data for each site for minimum and maximum temperature, rainfall, solar radiation, sunshine hours.
3. Latitude and Longitude of the site.
4. Most common variety of crops sown, plant population, row spacing, sowing depth, planting date and socio-economic crop data for validation.
5. For calibration and Validation of the DSSAT3 Model regional experimental data for a site is required.

### **C: DATA REQUIRED FOR THE GRASSLANDS/LIVESTOCK MODEL (SPUR2)**

- 1 30 years of continuous daily measurements for:
  - (a) maximum and minimum temperatures,
  - (b) precipitation (mm),
  - (c) wind run (Km/day),
  - (d) solar radiation (Langleys).
- 2 Soil Data:
  - (a) Soil name and texture,
  - (b) slope;
  - (c) percentage of sand, clay and silt;
  - (d) organic matter;
- 3 Parameters for universal soil loss equations;
  - (a) soil evaporation;
  - (b) bulk density; and
  - (c) water holding capacity at - 1/ and 15 bar.
- 4 For the selected site Biomass estimates for:
  - (a) green shoots,
  - (b) live roots,
  - (c) propagules,
  - (d) standing dead,
  - (e) dead roots,
  - (f) litter, and
  - (g) soil organic matter.
- 5 Also provide estimates of the amount of nitrogen (gm<sup>2</sup>) in:
  - (a) green shoots,
  - (b) live roots,
  - (c) propagules,

- (d) standing dead,
- (e) dead roots,
- (f) litter, and
- (g) soil organic nitrogen.
- 6 Livestock data:
  - (a) animal weight,
  - (b) estimate of genetic potential for gain,
  - (c) milk production,
  - (d) birth weight,
  - (e) weaning weight,
  - (f) yearly weight,
  - (g) mature weight,
  - (h) estimates of lifetime,
  - (i) growth curve weights,
  - (j) reproductive capacity, and
  - (k) forage intake;
  - (l) birthing dates,
  - (m) castration dates,
  - (n) weaning dates,
  - (o) breeding dates, and
  - (p) slaughter or sale dates;
- 7 Supplemental forage type and when fed, grazing systems, and herd structure.

**D: DATA REQUIREMENT FOR FOREST IMPACT ASSESSMENT**

1. A minimum of 30 years of annual Temperature and precipitation.
2. Identify major socio-economic tree species.
3. For each tree species to be simulated required data is:
  - (a) maximum observed height in meters;
  - (b) maximum observed diameter in metres,
  - (c) maximum observed age in years,
  - (d) shade Tolerance, and
  - (e) number of seedlings produced per year;
4. Other data
  - (a) Growing-Degree days (minimum and maximum),
  - (b) soil texture,
  - (c) soil water holding capacity, and
  - (d) slope and aspect of topography.

**E: DATA REQUIRED FOR THE WATER RESOURCES**

1. Monthly river runoff values for each river; mean monthly values of temperature and precipitation; total and elevation area values for the river basin.
2. Current water use for:
  - (a) agricultural,
  - (b) domestic;
  - (c) industrial, and
  - (d) energy-related sectors for each river basin;
3. current economic activity indicators for:
  - (a) agriculture
  - (b) domestic,
  - (c) industrial, and
  - (d) energy-related sectors for each river basin;
4. Estimates of economic activity level for the year 2010, 2020, 2030, 2040, 2050, 2060, 2070, 2080, 2090, and 2100 for:
  - (a) agriculture,
  - (b) domestic;
  - (c) industrial, and
  - (d) energy-related sectors;.
5. Estimates of technological changes in water use reflected in modified water use coefficients.

6. Estimates of current and future water resource infrastructure development, especially reservoir storage for each river basin; estimates of amount and potential inter-basin transfer for each river basin.
7. Estimates of adaptations and costs in water use and management at a coarse national and river basin scale.

**F: DATA REQUIREMENTS FOR THE COASTAL ONE (SEA LEVEL) ASSESSMENT**

1. Topographic Maps, Aerial photographs, Bathymetric maps of the near-shore, Tide gauge data, wave data, historical shoreline change data (erosion and accretion); and sediment impoundment through construction of dams or rivers, seawalls, and jetties.
2. Type and Cost of Physical infrastructure on the Coastal Zone
3. Heritage sites

**G: DATA REQUIREMENT FOR SOIL EROSION ASSESSMENT**

1. Daily maximum and Minimum Temperature, daily precipitation amount, daily solar radiation, monthly wind speed and direction at a 10m height and frequency of direction.
2. Soil depth, percent sand, percent silt, pH, percent organic carbon, and percent calcium carbonate.

**H: DATA REQUIRED FOR THE HEALTH ASSESSMENT**

1. Principal causes of mortality by age group; principal infectious diseases with incidence/prevalence data arranged by age group and geographic distribution;
2. populations living at low elevations in coastal ones and populations with poor or marginal drinking water quality, arranged by geographic distribution;
3. prevalence of malnutrition, arranged by age group and geographic distribution
4. general demographic data on income, education, geographically arranged with population growth predictions.
5. Current climate data, including minimum and maximum seasonal temperatures, precipitation levels average monthly temperatures by smallest geographical and political area possible;
6. predicted changes in above climate data from available GCM Models;
7. for infectious diseases, it may be useful to map vegetation types to assess suitability and continuity of habitats for vector species; also
8. for infectious diseases, information on surface water irrigation and other means of water distribution is useful.
9. Population and food intake data; GNP and government health investment levels.

**I: DATA REQUIRED FOR FISHERIES ASSESSMENT**

1. Air and water temperatures;
2. fishing intensity,
3. precipitation, surface water runoff; surface water area; lake levels; stream width; acidity or alkalinity of river; stream flow, flood duration, timing and magnitude; aerial extent of flood plain inundation; total annual rainfall,
4. mean annual air temperatures for shrimp fishery area of concern; sea level; salinity;
5. Species-specific ingestion, respiration and excretion rates,
6. species-specific asymptotic length and weight; annual fish yield;
7. location of known important fisheries habitat, such as spawning and nursery grounds;
8. timing of important species-specific life history activities, such as spawning and nursery periods;
9. annual productivity of river, type of fish population present, and fish food, production;
10. species-specific temperature preferences and maximum temperature tolerances;
11. historical annual catch for river reaches of concern;
12. species-specific habitat preferences, including water temperature and stream flow;
13. historic total annual shrimp catch for each shrimp fishery area of concern;
14. commercial shrimp yield for the shrimp fishery area of concern;
15. Aerial abundance of aquatic vegetation, depth requirements for vegetation and shrimp and annual shrimp yield, for each shrimp fishery area of concern;
16. aerial extent of existing inter-tidal and estimate vegetation for each shrimp fishery area of concern; and
17. Shrimp species-specific habitat preferences and life-history requirements (such as temperatures) for optional reproduction or growth.

### 3: DOCUMENTATION AND SOFTWARE ON THE VULNERABILITY AND ADAPTATION ASSESSMENT:

As far as possible complete documentation and software for the assessment tools and techniques was provided to the Vulnerability Assessment Task Team of Mozambique. The following tools and accompanying documentation were provided to the Team and reside in the DeskTop computer at the National Directorate of Environmental Affairs at MICOA.

<b>Sector</b>	<b>Model/Tool</b>	<b>Documentation</b>
<b>Baseline and Climate Change Scenario</b>	(1) GRADS Software (2) GCM Output data using MAGICC-SCENGEN	Documentation and instructions on how to execute the GRADs tool provided
<b>Crop Production - Agriculture</b>	(3) DSSAT3.5 and DSSAT3.0	Embedded in Model
<b>Forests and Forestry</b>	(4) Holdridge Life Zone Classification (5) Forest Gap Model	Embedded in the Model and lecture notes provided to Team
<b>Fisheries</b>	(6) Habitat Suitability Index (7) Bioenergetics (8) Maximum Sustainable Yield for Shrimps (9) Other Regressions Equations	Embedded in the Models and part of the lecture notes
<b>Health</b>	(10) TARGETS Model	The Coordinator to acquire from RIVM Group in The Netherlands.
<b>Water Resources</b>	(11) WATBAL (12) CLIRUN (13) RUNQUAL	Software and embedded documentation provided
<b>Coastal Resources</b>	(14) IPCC Common Methodology	Seven steps contained in the lectures provided during the training

### 4: TRAINING OF THE VULNERABILITY TASK TEAM OF MOZAMBIQUE

The Consultant provided training to the Vulnerability Task Team in the form of a Workshop that consisted of Power Point Presentations (see Annex III). After every presentation the Team is guided through the execution of the related Biophysical Model for the particular sector. During the workshop it was also agreed that after the data collection exercise is completed the Team members will try to run the models and where necessary the Consultant will be requested to make himself available for a period of about one week to assist the team.

## **5: RECOMMENDATIONS TO IMPROVE THE MANAGEMENT OF THE INVENTORY PROCESS AND THE NATIONAL COMMUNICATIONS PROJECT:**

Through this Consultancy, it is recommended that:

1. The Vulnerability Team makes every effort to collect as much of the required data as possible but should make more efforts to collect the complete set of the climate data of Mozambique;
2. The Models to be used have default data for some of the biophysical variables but the climate data should be collected since the Models run on altered climate data due to warming
3. The Team should provide references of all data and explain clearly the default values used in the assessment process;
4. The Team should develop a data bank for the storage of all the data collected during the process;
5. The Team should continue to conduct exercises and practice on the execution of the Models so that the methodologies remain fresh in their minds.

## **6: CONSULTANCY REPORT:**

This Consultancy Report consists of this write-up based on the ToR, the list of data required for the Training Workshop and the execution of the models (preceding Box), Workshop Report (Annex I) and Power Point presentations (Annex II).

# **ANNEX I**

## **NATIONAL TRAINING WORKSHOP ON ASSESSEMENT OF VULNERABILITY OF MOZAMBIQUE AND ITS ADAPTATION TO CLIMATE CHANGE:**

### **WORKSHOP REPORT**

**MR. BUBU PATEH JALLOW  
CONSULTANT AND TRAINER  
MOZAMBIQUE-NETHERLANDS CLIMATE  
CHANGE PROJECT**

# VULNERABILITY AND ADAPTATION ASSESSMENT WORKSHOP

17 TO 21 APRIL 2006, MAPUTO, MOZAMBIQUE

## WORKSHOP AGENDA

<b>DAY 1:</b>	<b>Wednesday</b>	<b>19 April 2006</b>
<b>Registration</b>		<b>08:00 – 10:00</b>
<b>Opening Ceremony</b>		<b>10:00 – 10:45</b>
<b>OVERVIEW OF THE V &amp; A ASSESSMENT PROCESS</b>		<b>10:25 – 10:35</b>
<b>Coffee/Tea Break</b>		<b>10:45 – 11:00</b>
<b>SESSION 1:</b>		
<b>DEFINING AND APPLYING SCENARIOS</b>		<b>11:00 – 13:00</b>
<b>Lunch Break</b>		<b>13:00 – 15:00</b>
<b>SESSION 2</b>		
<b>ASSESSMENT OF THE IMPACTS ON CROP PRODUCTION</b>		<b>15:00 - 16:00</b>
<b>End of Day 1</b>		<b>16:00</b>
<b>DAY 2:</b>	<b>Thursday</b>	<b>20 April 2006</b>
<b>SESSION 3:</b>		
<b>ASSESSMENT OF VULNERABILITY OF WATER RESOURCES AND EXECUTION OF THE DSSAT35 MODEL</b>		<b>09:00 – 11:00</b>
<b>SESSION 4</b>		
<b>ASSESSMENT OF VULNERABILITY OF RANGELANDS AND EXECUTION OF THE SPUR2</b>		<b>11:00 – 13:00</b>
<b>Lunch Break</b>		<b>13:00 – 14:00</b>
<b>SESSION 5:</b>		
<b>ASSESSMENT OF VULNERABILITY FOREST RESOURCES AND EXECUTION OF THE HOLDRIDGE AND GAP MODELS</b>		<b>14:00 15:30</b>
<b>End of Day 2</b>		<b>17:00</b>

**SESSION 5:**

**ASSESSMENT OF VULNERABILITY OF FISHERIES RESOURCES AND EXECUTION OF FISHEQ, HSI, BIOENERGETIC MODELS** **09:00 – 11:00**

**SESSION 6**

**ASSESSMENT OF VULNERABILITY OF COASTAL RESOURCES** **11:00 – 13:00**

**Lunch Break**

**13:00 – 14:00**

**SESSION 7:**

**ASSESSMENT OF VULNERABILITY OF THE HEALTH SECTOR** **14:00 – 15:00**

**MEETING OF THE TASK TEAM TO MAP THE WAY FORWARD** **15:00 – 16:30**

**End of Day 3**

**17:00**

## **THE TRAINING WORKSHOP:**

The Training was divided into the following Modules:

- 1: Overview of the Vulnerability and Adaptation Assessment
- 2: Development of Baseline and Climate Change Scenarios and
- 3: Sectoral Vulnerability and Adaptation Assessment for:
  - 3.1: Crop Production**
  - 3.2: Forests**
  - 3.3: Fisheries**
  - 3.4: Human Health**
  - 3.5: Coastal Resources**
  - 3.6: Water Resources and**
  - 3.7: Integrated Assessment**

In each of the sectors covered a Power Point Presentation was made in the morning that covered the assessment approaches and the tools available for use. The presentation was followed by execution of the Biophysical Models used as tools to conduct the Impacts Assessment and the Matrixes used for Adaptation Assessment.

### **1: OVERVIEW OF THE VULNERABILITY AND ADAPTION ASSESSMENT PROCESS**

Vulnerability and adaptation assessment is defined as an evaluation of how changes in climate may affect natural environment, national economy, and human health and welfare. The assessment involved the following steps.

- (i) Definition of the scope of the problem and assessment process;
- (ii) Definition and description of the scenarios underlying the assessment.
- (iii) Determination of the biophysical impacts by examining the effect of the baseline, climate change, and environmental scenarios.
- (iv) Evaluation of adaptation measures, practices and technologies
- (v) Integration of the results of each impact.
- (vi) Analysis of adaptation options, policies and programs; and
- (vii) Preparation and presentation of a report.

Addition steps to determine the proper scope of the assessment were also presented.

## **2: DEFINING SCENARIOS USING GENERAL CIRCULATION MODEL OUTPUT AND APPLYING THEM FOR VULNERABILITY ASSESSMENTS.**

This presentation covered the development of baseline climate and socio-economic scenarios, environmental scenarios and climate change scenarios.

During the discussions the Team agreed to use average climate to refer to the 30-year period 1961 to 1990 and the elements to be covered temperature, rainfall, solar radiation. Baseline socioeconomic scenarios discussed included population and income scenarios, environmental conditions (e.g., pollution levels, land-use, desertification and ecosystem health) and institutional scenarios

On the development of climate change scenarios participants were introduced to the three basic options that are available for creating climate change scenarios. These include General Circulation Model (GCM) outputs, analogue (historical) warm periods, and incremental changes in climate variables (e.g., +2<sup>o</sup>C, +4<sup>o</sup>C, ±10% precipitation).

### **GCM Scenarios**

General Circulation Models are mathematical representations of atmosphere, ocean and land surface processes based on the laws of physics. These models estimate changes for dozens of meteorological variables in regional climate in grid boxes that are typically 3<sup>o</sup> or 4<sup>o</sup> up to 10<sup>o</sup> (latitude and longitude).

Two types of GCM output are useful for vulnerability assessments. These are current climate (1\*CO<sub>2</sub>) and double CO<sub>2</sub> (2\*CO<sub>2</sub>) conditions. Almost all GCMs are run for current climate 1\*CO<sub>2</sub> and 2\*CO<sub>2</sub> conditions. The process also used output from transient scenarios, which run by assuming a steady increase in greenhouse gas concentrations and examining how climate could change over time.

Creating GCM-based scenarios is accomplished by combining average monthly changes between 2\*CO<sub>2</sub> and 1\*CO<sub>2</sub> from GCMs with the 30 year climate normal data sets. Transient scenarios are created by combining that data set with average changes from each decade of a GCM transient.

At least three GCMs should be used for assessing impacts of climate change. These three GCMs are selected by the following steps for creating climate scenarios.

1. Obtain 1\*CO<sub>2</sub> output from all available GCMs
2. Compare the regional 1\*CO<sub>2</sub> output with observed climate data.
3. Select the three (or more) GCMs that best reflect current climate.

Regional scenarios are then created by combining average monthly output obtained by taking the difference between equilibrium 2\*CO<sub>2</sub> and 1\*CO<sub>2</sub> runs with observed climate data from the 30-year baseline climate period. Add the change in temperature (2\*CO<sub>2</sub>-1\*CO<sub>2</sub>) to the observed temperatures and multiply ratio changes (2\*CO<sub>2</sub>/1\*CO<sub>2</sub>) in other variables by the observed values of the other variables

### **Analogue Scenarios**

The second option for creating climate change scenarios is to base them on historical warm periods.

### **Incremental Scenarios**

The final option for creating climate scenarios is to use incremental changes. These capture a wide range of potential climate changes and identify the relative sensitivities of sectors to changes in specific meteorological variables.

Incremental scenarios should be applied for the combinations of temperature and precipitation changes in Table 2.1. Incremental changes in temperatures and precipitation should be combined with the baseline climate data to create incremental scenarios.

<b>ΔT/ΔP (%)</b>	<b>+20C</b>	<b>+40C</b>	<b>+60C</b>
<b>-20</b>	<b>X</b>	<b>X</b>	<b>X</b>
<b>-10</b>	<b>X</b>	<b>X</b>	<b>X</b>
<b>0</b>	<b>X</b>	<b>X</b>	<b>X</b>
<b>+10</b>	<b>X</b>	<b>X</b>	<b>X</b>
<b>+20</b>	<b>X</b>	<b>X</b>	<b>X</b>

### **Atmospheric CO<sub>2</sub> Level Scenarios**

The levels of atmospheric CO<sub>2</sub> recommended for use in climate change scenarios are 355 parts per million (ppm) for 1990, 440 ppm for 2030, and 580 ppm for 2075. A linear interpolation is used to derive CO<sub>2</sub> values in other years.

### **Sea-Level Rise Scenarios**

The latest estimates for sea-level rise are for a 0.15 to 0.9m rise by 2100, and the most likely estimate is about 0.5m. The sensitivity of coastal resources to current sea-level rise (0.2m by 2100) and to accelerated rates of sea-level rise of 0.5 and 1.0m by 2100 should be tested.

## **3: TRAINING ON SECTORAL IMPACTS AND ADAPTATION ASSESSMENTS**

### **3.1: Crop Impacts and Adaptation Assessments**

#### ***3.1.1: Approaches used in the Assessments***

The primary approach for analyzing agricultural impacts consists of preliminary screening and simulation techniques.

#### **Preliminary screening**

Preliminary screening begins with an assessment of vulnerability to climate change based on expert judgement obtained by consulting in-country agricultural specialists. Such an assessment can provide a qualitative (or simple quantitative) analysis of potential impacts and adaptation.

The preliminary vulnerability assessment for agriculture could include the following:

- Identification of the crops, geographical regions, and rural populations most likely to be vulnerable.
- Description of the vulnerable crops, regions and groups as well as the reasons for their vulnerability.
- Analysis of analogous regions (e.g. warmer regions of the country) under current climate regimes to help identify implications for future response to climate change;

- Projections of the expected magnitude of the impacts, expressed qualitatively (e.g. positive negative, or no impact on crop yield); and
- Examination of potential adaptation measures with explicit study of their expected effectiveness and costs.

Key results can be summarized as in Table 3.1.1.

System	Characteristics Sensitive to Climate Change				Degree of Vulnerability	Adaptation Alternatives	
	Yield	Irrigation Needs	Susceptibility to Disease	Etc.		Type	Effectiveness, Cost
<b>Grain Crops</b>							
Wheat							
Corn							
Rice							
Sorghum							
Millet							
Etc.							
<b>Other Crops</b>							
Fruits							
Cassava							
Groundnuts							
Etc.							

### *The Simulation Techniques*

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and the International Consortium for Application of Systems Approaches to Agriculture (ICASA) network allows evaluation and dissemination of appropriate crop models and climate change impact methodologies so that country study teams can use specific weather, soil, and crop information to simulate the effects of climate change, thus identifying potential agricultural vulnerabilities. This approach was selected because the crop models

- (1) have been validated in a wide range of environments around the world
- (2) are easy to use;
- (3) have consistent inputs and outputs, which facilitate comparisons of results and
- (4) have a decision support system that allows comprehensive testing of climate change scenarios, increasing levels of CO<sub>2</sub> and farm-level adaptations.

The IBSNAT-ICASA models are made up of parameterizations of important physiological processes responsible for plant growth and development, evapotranspiration, and partitioning of photosynthate to produce economic yield. The functions help predict the growth of crops, as influenced by the major factors that affect yields, i.e. genetics and climate (e.g. daily solar radiation; maximum and minimum temperatures; and precipitation, soils and management practices). The models include a soil moisture balance sub-model, which allows them to predict both rainfed and irrigated crop yields. The cereal models simulate the effects of nitrogen fertilizer on crop growth. Changes in soil moisture can be compared with those calculated with water resource models. The Decision Support System for Agrotechnology Transfer (DSSAT), which is one such set of models, is a comprehensive software system that integrates crop growth models with crops, weather, and soil data and with various application programme.

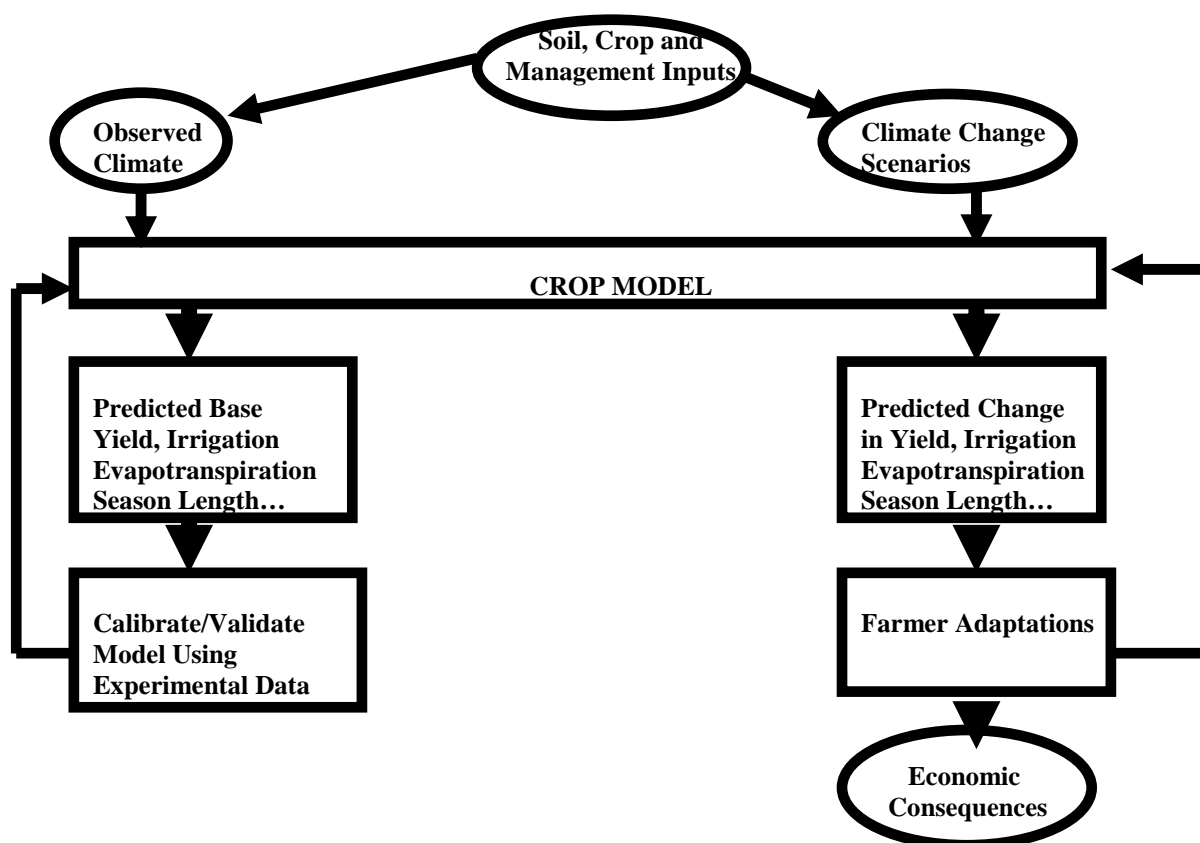
### ***3.1.2: Description of the Methodology***

Tasks for the agricultural scientists conducting the country study include:

- Specifying the soils and crop management inputs necessary to run the IBSNAT-ICASA crop models at the selected sites.
- Defining the geographic boundaries of the major production regions of the country and estimating the current production of major (both commercial and subsistence) crops in those regions.
- Providing observed climate data for representative sites within these regions
- Specifying the soils and crop management inputs necessary to run the crop models at the selected sites.
- Validating the crop models with experimental data from field trials.
- Running the crop models with the baseline-observed data and climate change scenarios, with and without simulations of the direct effects of CO<sub>2</sub> on crop growth, irrigated production (if applicable), additional sensitivity tests, and adaptation responses (planting date, appropriate varieties, or species).
- Reporting modeled yield (T/ha) changes and other results, that is, changes in season length (d), growing season precipitation (mm), growing season evapotranspiration (mm) and water used for irrigation (mm) arising from the climate change scenarios and other simulations.
- Identifying and evaluating alterations in agriculture practices that would lessen any adverse consequences of climate change.

- Collaborating with agricultural and resource economists to project the economic consequences of crop modeling results.
- Writing a report that describes the agricultural system modeled; the methods and results of the crop modeling work, including adaptation responses, the economic aspects of the study, and the implications of the projected climate, and yield changes on agriculture in the country.

A flow diagram illustrating the above tasks is given in Figure 3.1.1.



Crop modelers should choose the most productive agricultural regions in each country. These regions are defined as similar geographic areas of land, characterized by particular patterns of soil, climate, water resources, land use and type of farming. Studying two or more regions in each country is useful for examining regional differences in response to projected climate changes, provided that weather and crops data are available to validate and run the crop models.

Each agricultural scientist is to run the IBSNAT-ICASA crop model (s) for the baseline and climate change scenarios at each selected site, depending on availability of time and resources. CERES-Maize and other IBSTNAT-ICASA crop models have been modified to simulate the changes in photosynthesis and evapotranspiration caused by increase in atmospheric CO<sub>2</sub>. If irrigated production is widespread under the current climate, or if the climate change scenarios suggest drying for an agricultural region, both dry land and irrigated production should be

simulated. This scenario aids in giving a critical estimate of how the demand for water from agriculture may change as climate changes.

A complete assessment of the economic consequences needs to be conducted and this requires three types of information:

1. The differential changes that climate causes in production and consumption patterns (e.g., crop yields);
2. The responses of input and output market prices to these changes; and
3. The input and output changes that affected individuals make to minimize losses or maximize gains from changes in production and consumption opportunities and in the prices of these opportunities.

The screening techniques and crop modeling studies described above are the primary sources of information for the first requirement. Evaluation of the latter two requirements represents the economics portion of the benefits assessment. If an environmental change causes substantial changes in outputs, price and quality changes can occur, which, in turn, lead to further market-induced output changes. Quantitative analysis can be achieved by constructing simplified economic databases on in-country data.

Researchers in the country teams should first construct a simple checklist of available economic and agricultural information for the country. This information falls into three general categories: production, consumption and policy. Production information suggests the vulnerability of agriculture to climate changes or other environmental stress. This type of information includes

- (1) the number of alternative crops
- (2) the number of production techniques (e.g. irrigation),
- (3) the nature and extent of resources use in agriculture production, and
- (4) the cost of production information.

The first three categories of production information suggest the substitution possibilities in the agricultural sector. Specifically, the greater the number of crops alternatives and production techniques in a country, the greater the likelihood of adaptation possibilities. Conversely, for countries with few crops and few production techniques, the greater the potential vulnerability.

Important economic information includes the role of each crop in the country's overall food consumption; the percent of crops consumed domestically versus that, which is exported; and the price movements of commodities. The extent to which a crop contributes to domestic consumption has two potentially important effects. For example, a crop produced primarily for domestic consumption (i.e. a staple) is likely to be important to the well-being of both producers (in terms of their own consumption) and consumers. Reduction in the supply of such crops implies some increased vulnerability in terms of diet. A crop produced largely for export is typically a major source of foreign exchange earnings for the country. Reduction in exports can reduce the economic well being of both producers and others in the economy who depend on those export earnings (e.g. beneficiaries of government programs funded by the export earnings). As with production, countries with more crop alternatives in terms of both domestic and export use are less likely to be vulnerable to climate change.

These consumption and production effects are reflected in markets through the movements in prices for each commodity. Information on domestic price movements can reflect the degree to which crops are staples (highly inelastic demands). Price in export markets reflects international conditions. The nature of price and consumption information can thus signal the degree of vulnerability in a particular country.

Information on government policies toward the agricultural sector can indicate the extent to which economic adaptations are encouraged. Specifically, government intervention in agriculture (or other economic sectors) typically distorts economic processes. Removal of some government policies is thus expected to facilitate more rapid adjustment to environmental change. Conversely, increased government intervention implies less flexibility and perhaps greater vulnerability to climatic stress. Hence, some understanding of the present and future government involvement in the agricultural sector can be useful in forecasting potential vulnerabilities.

### ***3.1.3: Adaptation Techniques***

Many possible adaptation options appropriate for responding to climate change include altered planting dates; change to a crop more adaptable to the new climate; change to a crop more suitable to the new climate; change in the crop rotation pattern; application of fertilizer; application of additional irrigation water, if an irrigation system is in place; and installation of an

irrigation system, if one is not in place. These adaptation options can be tested by using the IBSNAT/ICASA crop growth models, which allow comparisons of climate change scenarios with and without the given adaptation. The crop models can also be used to explore the genetic resources needed to adapt to extreme climate change. The adaptation techniques listed in Table 3.1.2. should be evaluated with the crop models.

<b>Table 3.1.2: Adaptation Measures Recommended for Evaluation</b>
<b><i>Biophysical (with crop model)</i></b>
➤ Changes in Planting Dates
➤ Changes in Cultivar
➤ Application of irrigation
➤ Changes in levels of fertilization
➤ Changes in crop
<b><i>Economic</i></b>
➤ Substitution possibilities for other crops
➤ Availability and costs of alternative production techniques
➤ Alteration of level of government intervention in agriculture

#### **3.1.4: Data requirements**

Data requirements for the crops' impacts and adaptation assessments include

1. soil type (e.g. shallow, medium, or deep silty clay, silt loam; sandy loam or sand) with associated IBSNAT-ICASA soil characteristics for model runs at each site.
2. 30 years (or as long a record as possible) of daily weather data for corresponding periods at each site, including minimum and maximum temperatures, precipitation, daily solar radiation, daily sunshine duration or computer-simulated daily solar radiation for each site. A weather generator is embedded in the IBSNAT-ICASA decision support system and can be used to generate daily solar radiation and other climate variables.
3. Location data (elevation, latitude and longitude of site)
4. Crops data [(the variety commonly sown wheat, maize, soybeans, rice, sorghum, millet, barley, peanuts, beans, potatoes and cassava), plant population, row spacing, sowing depth, and planting dates]

## **3.2: WATER RESOURCE IMPACT AND ADAPTATION ASSESSMENTS**

### ***3.2.1: Approaches used in the Assessments***

The Primary Approach involves both preliminary screening and simulation techniques. A preliminary screening of the major sub-sectors of water resources vulnerability should be carried out to identify critical areas for detailed assessment. The simulation approach is an analysis of the joint impacts of population growth, economic development and climate change on regional water resources. The approach will have a four-step procedure that investigates:

- Impact on hydrologic resources-supply
- Impact on water uses-demand
- Impact on supply and demand balance-vulnerability, and
- Alternative management strategies-adaptation.

The primary approach is to be used in assessing a country's water resources vulnerability to climate change including supply, demand and management. Supply is analyzed in two stages.

- Stage 1 assesses river runoff impacts by means of one of the methods recommended below.
- Stage 2 assesses the effect of the impacted river runoff on the management of the water resource system and the resulting water supply.

Demand is analyzed on a very aggregated national basis.

A supply and demand balance for each river basin unit is undertaken and a measure of vulnerability is assigned. National vulnerability is assessed via a gross national supply-and-demand balance and by a restrictive basin method.

The scope of the analysis is on a river basin scale. The temporal scale is monthly for some analyses and annual for others. The monthly time scale appears to be the "optimal time step" for climate change assessments because it models the seasonal distribution and is large enough to avoid computational and data problems. For water demand, some uses (e.g. navigation, municipal, and industrial) can be estimated annually but others (e.g. environmental, hydropower, and irrigation) need to reflect the seasonal distribution.

### ***3.2.2: Description of the Methodology.***

The framework for assessing the impacts of climate change on national water resources and analyzing possible adaptation assessments is made up of four distinct components supply, demand, vulnerability and adaptations. A Water Balance Model (WATBAL), which is a monthly spatially lumped, one-dimensional water balance model is used to model the hydro-climatic cycle. To apply the model, a watershed is selected that has one or more stream flow measuring stations with ‘‘sufficiently’’ long records. The watershed area upstream of the stream flow stations is delineated, and weighed average values of precipitation and temperature are estimated.

In the model, PET can be estimated by using a variety of methodologies based solely on average monthly temperature and daily sunlight duration. Precipitation is divided into interception, percentage snow, direct surface runoff, and infiltration. The soil moisture zone is modeled as a nonlinear reservoir with discharge to the mouth of the watershed and no storage over the year or losses.

The impact to climate change is analyzed by inputting to the model-modified mean monthly temperature and precipitation values. The modified values are obtained by using GCM-generated monthly differences in temperature and precipitation between 2xCO<sub>2</sub> and 1xCO<sub>2</sub>. After selecting the most appropriate GCM grid cell for the watershed new input values are calculated. The model is run holding all parameters constant, and runoff estimates are generated. These new runoff values represent the estimate of the impact of the associated GCM scenario on water supply, both in terms of total annual supply and seasonal distribution.

Three key elements dominate estimating the impact of climate change on water demand: (1) the establishment of the ‘‘base’’ scenario (2) the assumption about technological improvements in water use sectors, and (3) the degree of adaptation possible on top of the projected base technological improvements.

In the methodology four aggregate water use classes are selected for the demand assessment: agricultural, domestic, industrial, and energy-related. For each river basin unit, current water use and associated economic activity data are collected. Per unit water use coefficients are calculated (e.g. domestic use-water per capita). Growth rates for each economic activity in the basin are then provided, and forecasts of economic activity are given for the base year.

To estimate water demand in the base year, multiply the forecasts of economic activities by a water use coefficient. A series of functions of water use versus some measure of development for different climate zones will be provided for the four economic activities.

After water supply and demand have been estimated for each river basin unit, vulnerability can be assessed. Basin supply and demand are entered into a spatial database tool (e.g. a GIS) and this tool calculates the water surplus or deficit. By using Shuval's vulnerability index, the vulnerability of each basin is then classified. Each basin is assigned a yield index. The yield index is a number between 0 and 1 that is multiplied times the natural water supply to reflect the amount of water that can be currently supplied to meet water demand. This index is based on the monthly distribution of water supply, the amount of installed reservoir storage capacity in the basin, and a measure of water distribution infrastructure. A new vulnerability classification using the effective water supply (yield index times natural water supply) is carried out. These analyses are carried out for the base and GCM scenarios.

Three levels, or scales of economic impact assessment, are proposed.

- The static direct sectoral impact in which water use in each sector (agricultural, domestic, industrial and energy-related) would be estimated on the basis of the water demand component. An economic value (GDP) of each of these activities is estimated for the base year and for the end of the simulation period. Increases or decreased in the water resource supply are equally allocated to each sector and the resulting changes in each sector are measured. This approach is very crude, but simple.
- Economic models of each sector can be developed with water as direct input to the sectoral production. This method would allow for substitution of water by other factors, which would more accurately represent economic behaviour.
- The previous two approaches attempt to measure the direct economic impacts of water. To measure the indirect economy-wide impacts, intermediate activities must be modeled. These activities do not directly use water, but use inputs from sectors that directly use water, such as cotton in the textile industry, hydropower in the aluminium industry, or navigation in the transport sector. Economy-wide input-output models are one approach.

### **3.2.3: Adaptation Strategies.**

At the national level, adaptation consists of supply and demand management. Supply management such as more capital investment in reservoirs and infrastructure, results in increasing the yield index and allowing for more interbasin water transfers. Demand management means reductions in water demand via investment in new water-saving technologies and changed use practices.

Because many aspects of both supply-and-demand management cannot be accurately represented by the yield index or basin-wide averages of water demand, one or more representative basin studies should be undertaken. The basin study takes a closer look at adaptation via supply-and-demand management of the detailed elements of the water resource system of the basin. Various river basin simulation models are available for such analysis.

Three basic adaptation measures are possible in the water resources sector: increase water supply, reduce water demand and manage supply and demand differently. Examples of possible adaptations are as follows:

- Increase water supply. Modify basin vegetation, construct reservoirs, drain swamps, reduce evaporation, develop groundwater resources and use interbasin transfers.
- Reduce water demand. Decrease the activities that require water, decrease the amount of water demand for each unit of economic activity, modify behaviours to use less water, reuse water and recycle water.
- Manage supply and demand differently. Modify cropping patterns so that water use better matches hydropower releases or natural flow patterns. Change recreational water use to match hydropower or agricultural needs. Change hydropower from a peaking to a baseload energy

### **3.2.4: Data Requirements.**

The assessment methodology requires substantial reliable data to lend credence to the results being generated.

- Monthly river runoff values for each river basin to be studies from local hydro-meteorological services

- Spatially averaged mean monthly values of temperature and precipitation covering the watershed of each river basin unit modeled for the time period that coincides with the time period from which the monthly stream flow values were calculated.
- Total and elevation area values for each river basin unit to be modeled.
- GCM-generated spatially averaged estimates of the changes in mean monthly temperature and precipitation due to 2xCO<sub>2</sub>.
- Current water use for agricultural, domestic industrial and energy-related sectors for each river basin unit: local hydro-met service.
- Current economic activity indicators for agricultural, domestic, industrial and energy related sectors for each river basin unit, local economic/information service or United Nations/World Bank database.
- Estimates of economic activity level for base year 2075 for agricultural, domestic, industrial and energy-related sectors for each river basin unit or annual growth rates: local economic/information service.
- Estimates of technological changes in water use reflected in modified water use coefficients: local economic/information service.
- Impacts of climate change scenarios on water use coefficients:
- Estimates of current and future water resources infrastructure development, especially reservoir storage for each river basin unit:
- Estimates of current and potential interbasin transfers for each river basin unit.
- Estimates of adaptations and costs in water use and management at a coarse national and river basin unit scale:

Also required are detailed hydrologic, engineering, economic, and institutional project data for current and future river basin components of the representative basin analysis. Reservoir storage for each river basin unit is also needed.

### **3.4: FOREST IMPACT AND ADAPTATION ASSESSMENTS**

#### ***3.4.1: Approaches Used in the Assessments***

**The Preliminary Screening Technique** can be used either as a first step to identify areas and/or species of greatest vulnerability or as a substitute for more quantitative analyses where insufficient data are available for model development and application. The initial step in any screening procedure is to identify factors within the scenarios (e.g. climate change) that may influence forest ecosystems. A number of climate indices are related to basic plant processes and vegetation distribution. Changes in the length of the growing season and thermal indices such as growing-degree days or absolute minimum temperatures directly influence species distribution and forest productivity. In addition to thermal indices, changes in patterns of precipitation directly influence plant productivity.

An important part of the preliminary screening process involves identifying areas critical to forest resources, such as conservation or production forestry areas. Furthermore, within these areas, critical species or groups of species can be identified. By examining the climate changes and other environmental features predicted by the global change scenarios, local experts can evaluate the susceptibility of the identified areas (or species) to the predicted changes in environmental conditions.

**The Simulation Techniques** for evaluating the potential impacts of climate change on forest ecosystems uses two simulation models: the Holdridge Life Zone Classification model and the Forest Gap model. The Holdridge model relates the current spatial distribution of vegetation to features of the climate system. This model is suitable for examining (1) broad-scale patterns of vegetation as they relate to climate and (2) the influence of climate changes on the suitability of a region to support different vegetation/forest types. The Forest Gap model is an individual-based model of forest dynamics that simulates the response of basic plant process to environmental conditions. The model can examine patterns of composition and productivity; however, it is site-specific and requires detailed information on the attributes of species and on site-specific factors.

Each of these models addresses a different feature of vegetation pattern. The Holdridge model provides a regional mapping system for interpreting spatial changes in climate patterns throughout the country or region. The Forest Gap model evaluates the temporal dynamics of a

given forested site in response to climate changes. Together the two models provide an integrated approach to evaluating regional impacts (Figure 3.2.1)

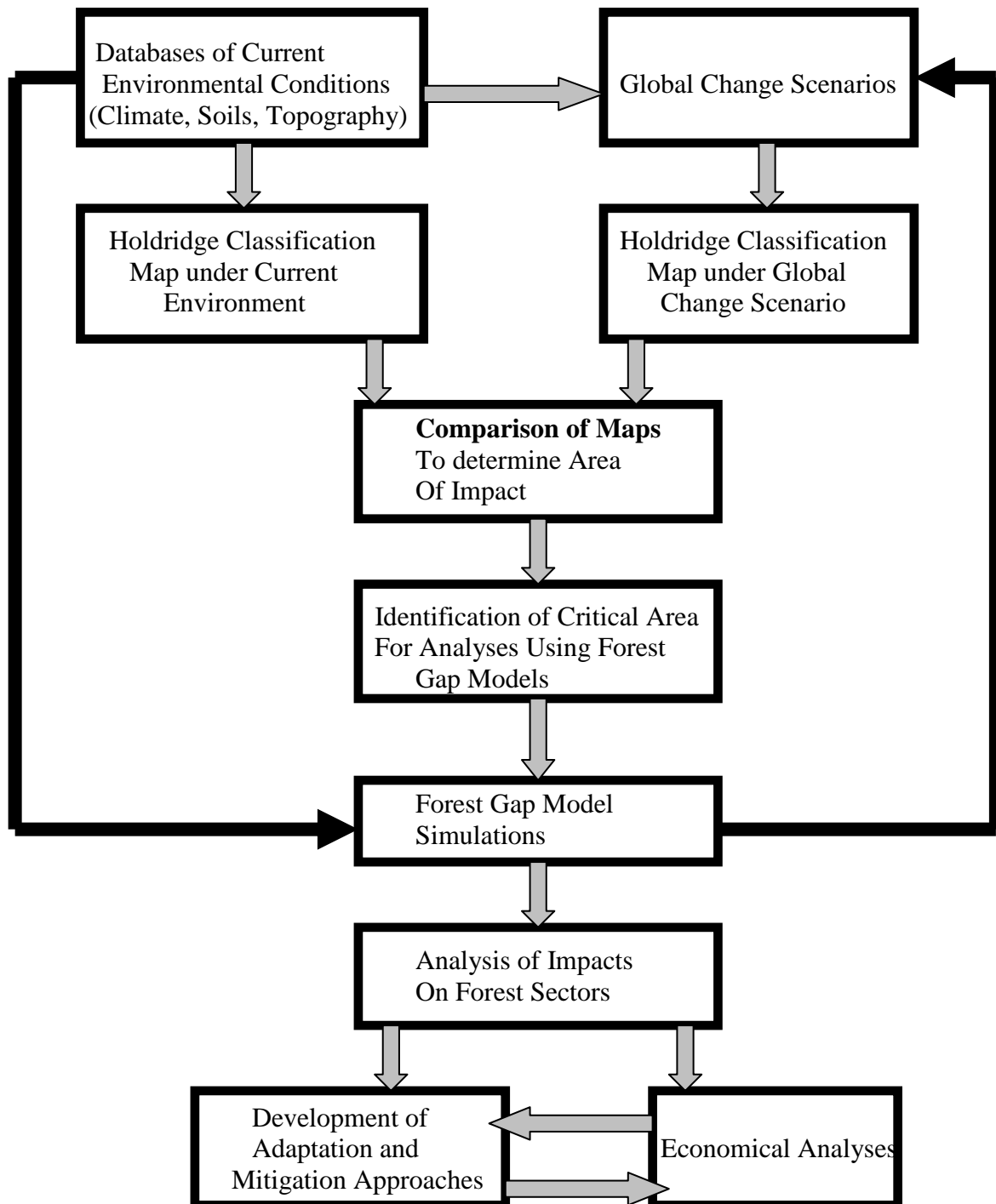


Figure 3.2.1: Flow Diagram Outlining the Steps Involved in Implementing the Forest Impacts Assessment

### 3.4.2: Description of the Methodology

#### Holdridge Life Zone Classification Model

The Holdridge model (Figure 3.2.2) is a climate classification scheme that relates the distribution of major ecosystem complexes to the climatic variables of biotemperature, mean annual precipitation, and the ratio of PET to precipitation. The life zones are depicted by a series of hexagons in a triangular coordinate system. Two climate variables - biotemperature and annual precipitation - determine the classification. Biotemperature is a temperature sum over a year with the unit temperature values (i.e., average daily, weekly, or monthly temperatures) used in computing the index set to 0°C if values are less than or equal to 0°C.

Identical axes for average annual precipitation form two sides of an equilateral triangle. The PET ratio forms the third side, and an axis for mean annual biotemperature is oriented perpendicular to its base. By striking equal intervals on these logarithmic axes, hexagons are formed that designate the Holdridge life zones.

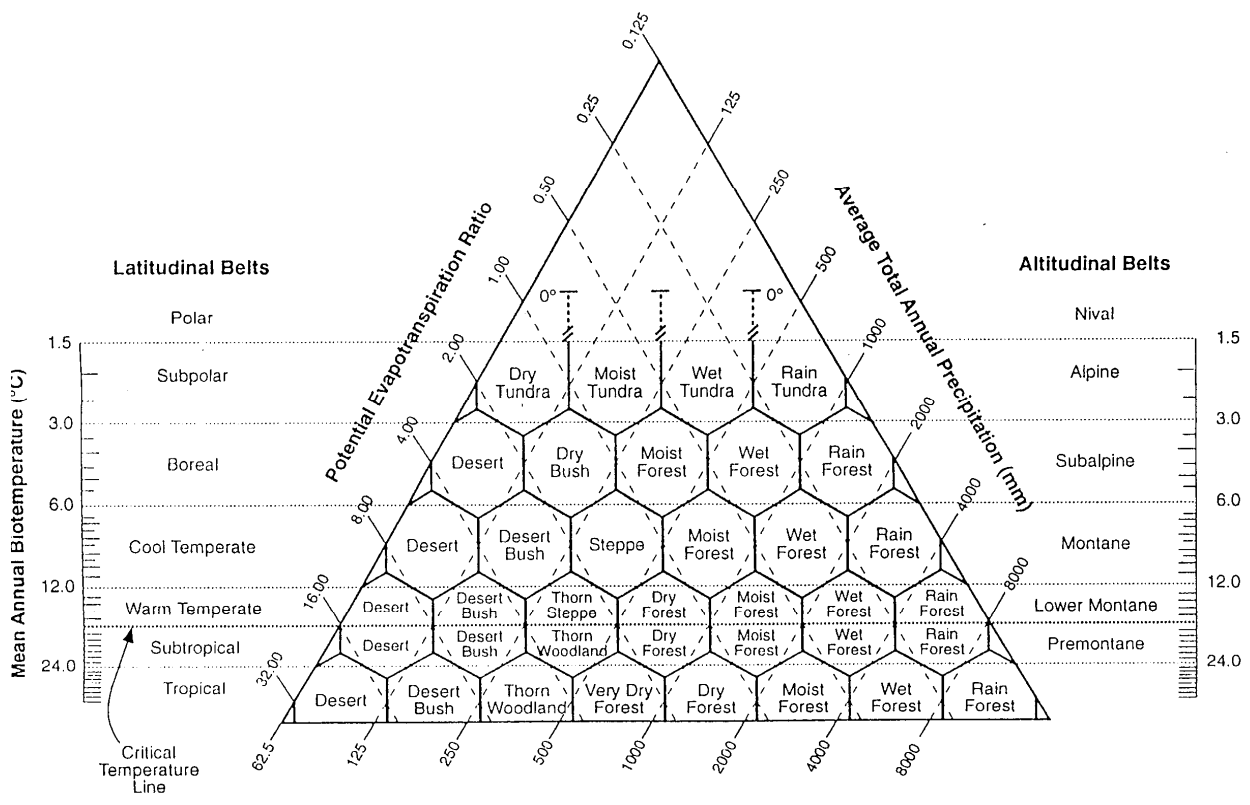


Figure 3.2.2: Holdridge Life Zone Classification Scheme

Implementation of the Holdridge model for a region requires only data on annual precipitation and biotemperature for a grid network based on latitude and longitude. Biotemperature is calculated from mean temperature values at either a daily, weekly, or monthly resolution. The values of mean annual precipitation and biotemperature are then used to classify each grid cell to determine the potential land cover based solely on climate. The resulting database of potential land cover (life zones) can be mapped, providing a base map of the country.

The map based on the Holdridge model represents the potential distribution of vegetation based solely on climate. This map should be compared with existing maps of vegetation for the region to incorporate other features of the environment that may influence vegetation pattern by modifying the two primary climate variables (biotemperature and annual precipitation). Factors such as variation in topography (e.g., slope and aspect) and soils can modify the moisture and temperature conditions from those characterized by the statistics for a given grid cell.

The changes in climate patterns predicted from the GCMs discussed in Section 2 can be easily incorporated into the modeling framework. The changes in monthly temperature and precipitation predicted by the GCM are used to modify the data on current patterns of annual precipitation and biotemperature used to generate the initial map of land cover for the country or region. By using the new values of biotemperature and annual precipitation for each grid cell, the Holdridge model generates a new map of predicted vegetation cover based on the changed climate conditions. This new map can be compared with the original map used on current climate patterns to examine potential shifts in vegetation distribution under the change climate patterns.

The Holdridge model can be applied at any spatial resolution, but analyses of regional impacts require the highest possible resolution. Global analyses have been undertaken at a spatial resolution of  $0.5^{\circ} * 0.5^{\circ}$  (latitude and longitude); however, this rather coarse spatial resolution may prove inadequate for regional analyses of vulnerability and development of adaptation/mitigation strategies.

### ***Forest Gap Model***

The Forest Gap model evaluates changes in the species composition and productivity of specific forested sites. Forest Gap models simulate the establishment, growth, and mortality of individual

trees on a forest stand (<1 ha) on an annual time step. Because the model simulates the response of individual trees on a forest plot, it can predict changes in species composition, forest structure (e.g., size-class distributions) and productivity. In addition, the model incorporates forest management practices (e.g., selective cutting and stand thinning), which allows for evaluation of adaptive strategies.

The potential growth of each tree is estimated from species-specific optimal growth curves. These growth curves are derived from either field data or estimated from simple silvicultural data on maximum tree size and longevity. Forest Gap models have been developed and applied to a variety of forest ecosystems around the world, ranging from tropical to boreal forest.

The Forest Gap model can simulate species composition and structure on an annual basis. The model can either simulate forest growth on bare soil, or it can be initialized for a given forest by defining the numbers, species and sizes of trees to be simulated.

Validation of the model for a given region is an important step in implementing the model for a new region. Validation generally involves comparisons of the simulated patterns of forest composition and structure to some independently collected (not used for model parameterization) set of field data describing the forest (e.g., age or size class structure, relative species abundance, and biomass).

Because Forest Gap models simulate the temporal dynamics of forests in response to environmental conditions, a transient climate change scenario should be incorporated into the modeling framework. The annual changes in monthly temperatures and precipitation from the transient scenario are used to modify the environment conditions on the forest stand, and the response of individual trees to those changes is simulated.

### ***Integrating the Holdridge and Gap Models.***

The two model approaches can be integrated in two ways for the following purposes:

- To examine the general agreement between predicted patterns of changes in vegetation cover from the Holdridge model with changes in species composition predicted from the Forest Gap model and

- To examine the rates of expected changes for the predicted changes in vegetation cover from the Holdridge model.

Initially, sites are selected in areas where the Holdridge model predicts shifts in vegetation cover (e.g., forest to grassland or change in forest type) under the scenario. By applying the gap models to these sites, The model predictions can be tested for general agreement. For example, if the Holdridge model predicts a shift from forest to grassland, the Forest Gap model should predict an increase in mortality and decline in productivity for the site. This integrated analysis also estimates the temporal dynamics associated with the predicted shift in vegetation cover. These estimates are particularly important in developing adaptation strategies and assessing economic impacts.

The application of Forest Gap models to specific forested sites depends on the availability of basic silvicultural and site data. Investigators may focus on commercially important species or areas of particular importance for production forestry or conservation. Combining the two modeling approaches allows for a systematic analysis of the impacts of climate change. Because the Forest Gap models have limited application to large areas, a sampling strategy should be developed to define sites at which to apply the Forest Gap models. Two criteria should be used. First, areas of particular importance (e.g., forestry and conservation) should be mapped and sites established for model simulations. Second, the maps of vegetation change under the scenarios generated by the Holdridge model should define areas of vulnerability. These areas may be currently forested areas that are predicted to decline under the changed climate conditions.

The analyst of impacts should include multiple scenarios. Given the large degree of uncertainty in the regional results of GCMs the greater value in evaluating the potential impacts of the various climate change scenarios lies in examining the sensitivity of the forested areas within a region. Sensitivities examined include changes in the regional climate system, particularly increases in temperature and possible associated drying.

An economic analysis of the impacts of climate change on forest resources requires information on both the impacts on supply and subsequent impacts on pricing of timber and other forest products. The two modeling approaches outlined for impacts assessment can provide different levels of information for assessing changes in the production of forest resources. Simple

analyses can be performed by overlapping areas of forest impact from the Holdridge model with areas of current forest production. This procedure can identify areas currently used for production forestry, but are predicted to change to some other type of land cover that is incompatible with timber production (e.g., shrubland, grassland). This approach together with the screening techniques discussed above, can provide a coarse resolution qualitative assessment of impacts on the supply of forest resources.

In contrast, Forest Gap models can perform more detailed analyses. These models can directly evaluate changes in productivity and timber production for specific areas under the climate change scenarios. They can predict changes in timber production by species and therefore provide detailed input of changes in supply for economic models.

The second requirement for an economic analysis is to evaluate the impacts of changing supply on pricing of timber and other forest products. Models must consider regional patterns of forest product utilization (e.g., fuel wood, saw timber, pulp) and foreign markets. In the latter case, the analyses must view how changes in supply in other regions influence market pricing. Even where prices are constant changes in supply are needed to evaluate the economic feasibility of adaptation strategies (e.g., changing land use, changes in management, or harvest practices).

### ***3.4.3: Adaptation Techniques***

Both models can be used to develop adaptation strategies. The land cover maps derived from the Holdridge model identify areas suitable for future forest production, but currently used for other purposes (e.g., agriculture). Identifying possible changes in the suitability of land use allows for planning future land use policies. Such policies could offset impacts due to possible declining productivity in current forest management areas under the changed climate conditions.

The Forest Gap models directly evaluate specific forest management strategies (e.g., changes in rotation time or cutting practices). In addition, they evaluate the response of individual species to the climate change scenario, which allows for development of management plans that favour a given species (e.g., selective cutting) that may be more resistant to the predicted climate changes. Another option is to use the model to evaluate the introduction of species from other areas suitable to the new environmental conditions.

#### **3.4.4: Data Requirements**

Data required for the assessments of impacts and adaptation of climate change in forests include:

1. Monthly Temperatures and Precipitation
2. Estimates of Potential Evapotranspiration
3. Moisture Deficit (PET-AP), AET/PET, Drought-days, Growing-Degree Days
4. Global Climate Data
5. Biotemperature
6. Species growth and environmental response data (Maximum Observed Height (m), Maximum Observed Diameter (m), Maximum Observed Age (m), Shade Tolerance)
7. Soil (e.g., texture and water holding capacity), and topography (e.g., slope and aspect).

### **3.5: FISHERIES VULNERBILITY AND ADAPTATION ASSESSMENT**

#### **3.5.1: Approaches Used in the Assessments**

A literature review identified three general approaches that have been used to evaluate potential impacts to fisheries resources from climate changes. These are:

- (1): predicting changes in the availability of thermal structure of lakes and streams;
- (2): predicting effects of temperature changes on fish physiological processes, particularly growth and feeding using bioenergetic Models; and
- (3): predicting impacts of changes in physical habitat features (i.e., water temperatures, flow rates, and water levels) to important life history stages such as migration periods and spawning times.

These general approaches have been identified by some researchers as the basic framework for evaluating climate change impacts on fisheries resources.

The variety of methods identified reflect the variety of climate factors that can affect fisheries resources, the variety of aquatic habitats that may have to be evaluated, the availability or lack of existing data and technical capacities, and the lack of a simple methodology or tool that can be used for all fisheries resources and evaluate multiple climate variables. In addition, the use of multiple methods will produce a more robust vulnerability assessment than an approach using only a simple method.

The major aquatic habitats of the country have to be evaluated separately for responses to climate change. In addition to this diversity of habitats, a variety of ecologically and/or economically important species occupy these habitats and may have to be considered with regards to potential climate change impacts.

Because of this great diversity in habitats and species as well as the diversity in the habitats and species that any single country may have to consider, no single assessment approach is suitable for use by all countries or for all aquatic habitats.

A preliminary screening technique is applied to identify and prioritize those fisheries within a country for which detailed vulnerability and adaptation analyses might be needed. In many cases, expert judgement can be applied to the fisheries to rank their vulnerability to potential changes in precipitation, temperature, or sea level rise as low, moderate, or high. All fisheries ranked as highly vulnerable should be considered for detailed analyses. Fisheries that have high economic or ecological importance and are ranked as moderately vulnerable should also be considered.

### ***3.5.2: Description of the Methodologies***

In general all the methods involve:

1. use of General Circulation Model Predictions of air temperature, precipitation, solar radiation, and wind;
2. identification of coastal marine and freshwater conditions vulnerable to climatic changes such as increased water temperatures, reduced dissolved oxygen levels, altered lake and sea levels, changed river hydrographs;
3. identification and collection of appropriate data, including historical limnological and climatological data, historic flow (hydrograph) data, morphometric/bathymetric data, and topographic information (maps, aerial photography);
4. implementation of assessment approaches including prediction of surface water temperature from air temperature, prediction of DO profiles, prediction of sea levels and river hydrographs, quantification of physical changes in habitats due to changes in sea levels using topographic information and quantification of areal extent of floodplain inundation;
5. prediction of changes in Marine and Freshwater conditions;

6. identification and collection of appropriate biological and fisheries data including physiological parameters (thermal niche and tolerance, DO requirements), habitat requirements (flow, substrate, depth) and other life history information, individual process rates (growth and mortality rates), and historical fish yield to catch estimates;
7. development of Habitat and Catch/Yield Models including empirical models relating fish yield or catch with habitat or climatic factors, habitat suitability index, relationships between population abundance and thermal habitat, and temperature-process relationships and predict process responses;
8. implementation of assessment approaches such as prediction of fish yields from empirical models and GCM climate predictions, prediction of fisheries response to changes in habitat availability, prediction of fisheries response to changes in habitat quality and evaluation of changes in growth using bioenergetics model and prediction of changes in temperature; and
9. finally, prediction of impacts on Fisheries Resources.

The following specific methods have been used and are recommended to the Assessment Team

#### **A. Assessing the Effects of Temperature on Productivity**

This method evaluates the annual productivity, K, of a river on the basis of average stream width, W, the biogenic capacity, B, of the stream, average annual temperature, k1, the acidity or alkalinity, k2, of the water, and the type of fish population, k3, present in the river. The productivity is calculated from the relation:

$$\mathbf{K \text{ (kg/km of river)} = B * L * (k1*k2*k3)}$$

Values of B can range from 1-3 for waters with little food, 4-6 for average waters, and 7-10 for water rich in fish food. The value for k3 can be approximated on the basis of the percent of rheophilic (flowing water) and limnophilic (quiet water) species in the fish community using the following relation:

$$\mathbf{K3 = (2L + R)/100}$$

Where L = percentage of the fish community comprised of limnophilic species, and R = the percentage of the fish community comprised of rheophilic species. These equations can be developed in the EXCEL Spreadsheet. Water temperature can be estimated from air temperatures using regression analysis to develop predictive model for water temperature. Mean stream width can be determined from flow and stage data and topographic maps.

Results are available for annual productivity estimated for current and predicted water temperatures. Vulnerability is assessed by comparing estimated annual productivity under historic and predicted climate scenarios.

### **B. Assessing the Effects of Temperature and Growth and Feeding**

The method uses the Bioenergetics Model 2. Climate Change impacts on fisheries resources are inferred comparing Bioenergetics Model 2-predicted growth and feeding rates and biomass production for historic and predicted temperature conditions. Regression analysis is used to develop models for predicting water temperatures from air temperatures.

Results generated are predicted growth and feeding rates of individual species, and biomass production for the entire resource, under historic and predicted temperatures. Vulnerability is assessed by evaluating the differences in growth and feeding rates and biomass production between historic and predicted temperatures. Results for individuals can be extrapolated to the resource as a whole.

### **C. Assessing the Effects of Temperature and Habitat Suitability – Temperature Tolerance**

This species-specific approach compares predicted maximum water temperatures to species-specific temperature tolerance and preference. Water temperatures will be estimated from predicted air temperatures using regression analysis.

Monthly or weekly predicted maximum temperature profiles will be developed for selected river predictions. The predicted temperatures will be compared to species-specific preferred temperatures and upper tolerance. This procedure will quantify the amount of riverine habitat that is unsuitable for a particular species on the basis of its thermal biology. Vulnerability

will be assessed by comparing amounts of unsuitable habitats for selected species in selected river locations.

#### **D. Assessing the Effects of Precipitation (as Stream flow) on Life History Parameters**

In this species-specific approach, predicted changes in the annual hydrograph for a particular river are compared to the historic or current hydrograph, and effects on spawning, growth, and recruitment are qualitatively inferred from the predicted differences in the timing, magnitude, and/or duration of flooding events, as well as differences in minimum and maximum flows. A stream hydrograph is a graphical representation of changes in stream flow over time.

Vulnerability assessment will involve the development of historic and predicted hydrographs for specific river reaches and identification of important life history parameters (spawning period, nursery period) will be identified on each hydrograph. Vulnerability is assessed by comparing changes in major hydrograph components (such as timing, magnitude and duration of flood events, relative to the timing of important life history parameters (spawning, nursery period) under historic and predicted precipitation scenarios. The greater the difference between the historic and predicted hydrographs relative to spawning and nursery periods, the greater the potential for adverse impacts to the fishery.

#### **E. Assessing the Effects of Precipitation on Catch**

##### ***E.1: Catch vs. Floodplain Area***

This approach uses regression analysis to develop empirical models to predict Catch. In the absence of sufficient historic catch and floodplain data, either of the following relationships may be used:

**I.      $C = 2.65A - 0.98$             ( $r^2 = 0.828$ )**

**II.     $C = 3.83$                       ( $r^2 = 0.865$ )**

Where C = annual catch (metric tons) per km reach of river and A = floodplain area (km<sup>2</sup>) per km reach of river. Historic flood and catch data should be used to determine which equation to use.

### ***E.2: Catch vs. River Discharge***

Fish production has been found to be positively correlated with river discharge, and potential effects of precipitation changes can be evaluated using relationships between river discharge and catch. The following relationship was developed between mean total catch (as a 3-year mean) and mean river discharge (3-yr mean) of the Niger River at Mopti:

$$\text{III. } Y = 29.338 + 0.075X \quad (r^2 = 0.988)$$

Where Y = total catch (metric tons, average over 3 years) and X = mean river discharge (averaged for the same 3-year period). In this approach, regression analyses will be employed using historic discharge and total annual catch data to develop predictive models of the form described above.

The vulnerability is assessed by estimating discharge and floodplain area for predicted precipitation regimes. Total catch is estimated by inputting the predicted floodplain area or discharge to the appropriate empirical model. Comparing historic annual catches with predicted catches for the different climate scenario precipitation regimes will give vulnerability.

### **F. Assessing the Effects of Precipitation, Temperature, and Dissolved Oxygen on Habitat Suitability Using Habitat Suitability Models.**

This species-specific approach includes the development of Habitat Suitability Index (HIS) models for individual species of concern. The models may incorporate environmental variables such as water temperature, current velocity, floodplain inundation duration, dissolved oxygen (DO) concentrations, and substrate composition, and produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable).

Following construction of species-specific HIS Models, habitat suitability indices will be estimated for specific habitats using historic (or current) climatic, hydrological, and ecological data. Suitability indices will then be calculated for the predicted climatic and hydrological conditions associated with each climate change scenario. Vulnerability will be assessed by comparing historic and predicted HIS estimates.

## G. Assessing the Effects of Temperature Change on Shrimp Yield.

The basis for this approach is development of regression equation of the form

$$\text{Log}_e k_i = a - b(1/T_I)$$

Where  $k$  = rate constant,  $T$  = absolute temperature ( $^{\circ}\text{K}$ ), and  $a$  (y-intercept) and  $b$  (slope) are coefficients estimated by regression analyses. Using empirical data from several sources, Regier et al. (1990) developed the following model for penaeid shrimp yield:

$$\text{Log}_e \text{SCSY} = 52.0 - 14312(1/T)$$

Where SCSY = stabilized commercial shrimp yield (kg/ha of intertidal vegetation) and  $T$  = mean annual air temperature ( $^{\circ}\text{K}$ ). An EXCEL version of this equation is developed for application.

GCM-predicted temperatures will be input to the models to predict shrimp yields under different temperature scenarios. Vulnerability will be assessed by comparing historic yields and predicted yields under each climate scenario.

Commercial and recreational fisheries lend themselves to economic analysis. However, subsistence fisheries for the most part operate outside the money economy. Therefore, traditional economic analysis is unlikely to be the most relevant approach for analyzing societal impacts of changes in these fisheries.

### 3.5.3: Adaptation Techniques

For freshwater fisheries, adaptation in response to climate change might require increased stocking, perhaps with non-indigenous species. Habitat improvement could enhance the fish resource, while changes in equipment could enhance the efficiency with which the resource is utilized.

Adaptation techniques for species that depend on coastal wetlands, and would be adversely affected by sea level rise, include restoration of degraded wetlands and construction of new wetlands. In some places, it might be possible, however, to supplement these resources through aquaculture. Using bigger boats or moving processing plants might enhance economic utilization of these resources.

#### **3.5.4: Data Requirements**

Some common physical data requirements include air and water temperatures, hydrological variables such as precipitation and runoff; and topographic and bathymetric data. Fisheries and biological data, sometimes species-specific, will also usually be required.

Specifically, the following will be required:

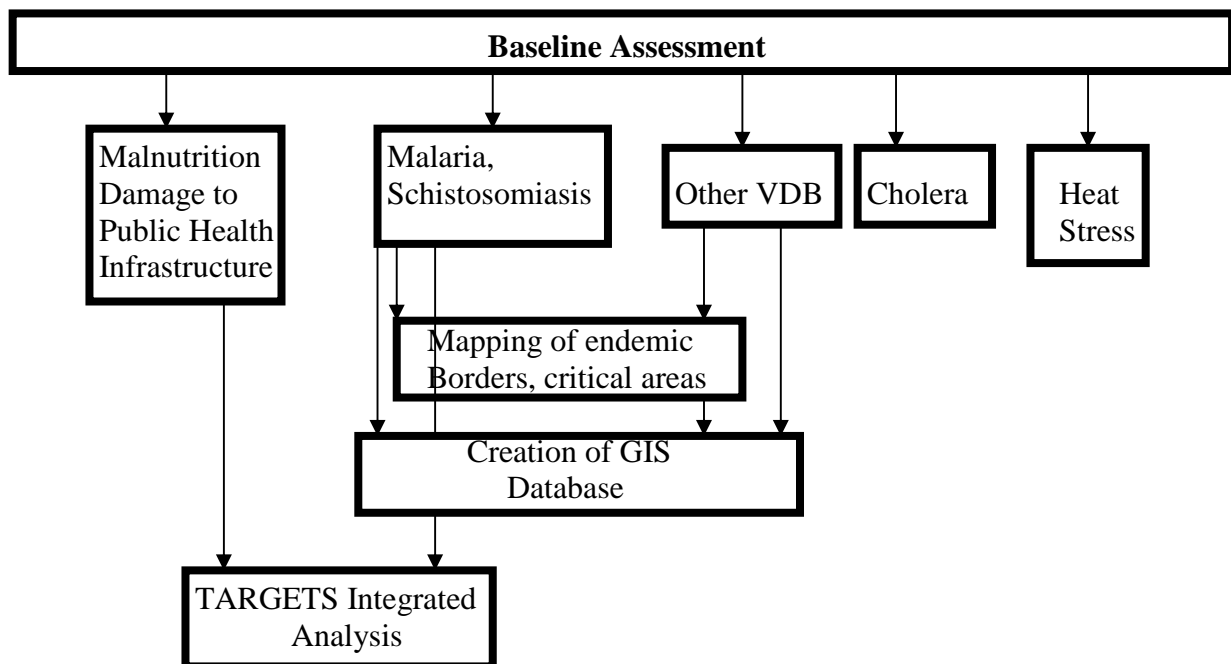
- (a) estimates of food resources available for the river segment of concern, alkalinity data, average stream width data, current annual productivity estimates,
- (b) Species-specific physiological data for each species of interest, including consumption, respiration, and egestion/excretion data, species upper thermal tolerance and preferred temperature, historic hydrograph data identifying stream flow, flood period and duration for area of concern.
- (c) Life history data on spawning period, nursery period, spawning and nursery habitats, and flow preference for species of concern.
- (d) Hydrographs for predicted precipitation scenarios indicating timing, magnitude, and duration of flood periods.
- (e) Historic discharge, floodplain area, and catch data; and predicted precipitation, surface runoff, flow and discharge data.
- (f) Species-specific habitat and physiology data, Habitat characteristics, including but not limited to temperature, DO, substrate, stage, and flow; and predicted temperature and precipitation data.
- (g) Historic data on shrimp yield in kg/ha of intertidal vegetation, historic mean annual air temperature, and predicted mean annual air temperature.

### 3.6: HUMAN HEALTH VULNERABILITY ASSESSMENT

#### 3.6.1: Approaches used in the Assessments

A multi-tiered approach is used to conduct impact assessment on the Health sector. The first stages use expert judgment and relatively simple data collection to make broad inferences about likely consequences of climate change for health in a given region or country. The latter stages use more sophisticated analytic and modeling tools to attempt more quantitative and integrative analysis. While such integration of multiple factors is an essential ultimate goal of predictive modeling, our poor present understanding of many of the interactions increases the possibility that such integration will result in large errors.

The initial step in vulnerability assessment is the baseline assessment survey (Figure 3.4.1). The purpose of this survey is to comprehensively review the country's current public health problems from the standpoint of sensitivity to climate change. All areas of public health including nutrition, sanitation/environmental health, infectious diseases, and principle causes of morbidity and mortality should be reviewed to avoid an early focus on one area that may not have the greatest public health significance.



It is important that a multi-disciplinary team perform the initial survey. Government and academic public health professionals, environmental engineers, sociologists, and agricultural experts all have a role to play in performing the baseline assessment.

Because human health is ultimately dependent on the integrity of natural and managed ecological systems and human social systems, changes in global climate are likely to affect human health through alterations in other sectors of the country studies project, such as agriculture, water resources, coastal resources, fisheries, grasslands and livestock. To the extent that vulnerability assessments are available, the results for these sectors should be included in baseline assessments.

The baseline assessment survey is expected to give a broad overview of health problems within a country that may be exacerbated by climate change, as well as to identify those areas and populations that are likely to be most affected by climate change. Thus a matrix consisting of the most serious current health problems arranged by their anticipated sensitivity to climate change should be created to help prioritize regions or problems for further vulnerability assessment. The marginal zones around areas endemic for vector-borne diseases should be delineated. Maps and geographic information systems should be developed to identify sensitive regions and sub-populations.

### ***3.6.2: Description of Methodologies***

#### ***Simple Mapping Studies***

Maps or plots of disease incidence or prevalence, geographic features that form boundaries, demographic data, current climate data, and climate predictions can be created and compared to make inferences about critical areas of susceptibility. The result of the mapping exercise should be the identification and characterization of geographic areas that are most susceptible to climate-related changes in health, primarily because they lie on the other side of a geoclimatic border from an area of high disease activity. The mapping exercise can be used to direct further field work in assessing a given disease's dependence on climate, locate areas in need of surveillance and monitoring facilities, or locate areas in need of health care or other interventional facilities. In general, mapping will be most appropriate for analyzing vector-borne disease.

The main limitation of mapping is that it does not provide a quantitative estimate of the impacts of climate change on human diseases. Also, without analytics, mapping is unable to provide an integrated assessment of the various factors influencing human health, although factors relevant for a given region can be identified through this process. Lastly, as with all analyses of climate change impacts, the availability of appropriate data is likely to be limited.

### ***GIS and Remote Sensing***

In addition to the creation of analog maps, a geographic method of organizing and storing data on disease incidence, vector populations, demographics, and climate with linkage to specific geographic locations will facilitate both vulnerability assessments and future research into climate disease linkages. The use of GIS system for prediction of disease incidence is still under development, but especially in combination with satellite remote sensing, there appears to be promise in using ecosystem parameters such as vegetation types to help predict where disease outbreaks might occur. It should be stressed that GIS systems will not provide higher quality outputs than the quality of the data that is entered into them, therefore attention needs to be paid on the proper collection and organization of the data before computerized analyses is initiated.

### ***Integrated Modeling***

Integrated mathematical modeling may be one method of addressing the limited success of traditional methods of epidemiology in accurately predicting climate-related changes in human disease, especially vector-borne diseases. To date, the models which have been developed are still in the process of validation, but they can be used in conjunction with the other methods of vulnerability assessment to investigate the range of possible outcomes and the potential impacts of various socioeconomic factors, such as population migration, malnutrition, and resource investment.

A model chosen frequently by country studies participants is the TARGETS (Tool to Assess Regional and Global Environmental and health Targets for Sustainability) models, developed by the National Institute of Public Health and Environmental Protection (RIVM) of The Netherlands. TARGETS Model uses a systems approach to interrelate social, economic, and environmental forces in predicting the behavior of human diseases or other human behaviors. Global Circulation Models (GCMs) generate climate data. Linked to the Integrated Model include modules for land and water use, energy resource development, population growth, and toxic chemical release. The use of a systems approach that includes inputs of societal factors

allows exploration of the relative impacts of different levels of population growth, resource allocation, and energy use, among other human factors. These factors can be dynamically modeled or input as fixed projections based on available data sources such as the FAO. For country studies, scaled-down disease-specific modules for malaria and schistosomiasis have been created which dynamically model population growth, nutrition and other disease (i.e., measles, diarrhea) but use fixed projections for other areas such as land use, water resources, etc.

Unlike other sectors whose products are inherently economic in nature, such as agriculture and water resources, human health is historically difficult to quantify and associate with economic value. Nonetheless, there are techniques to try to describe human disease in terms of its economic impact. Changes in disease incidence for different diseases can be compared by estimating lost productivity due to the disease.

### ***3.6.3: Adaptation Assessment Techniques***

Just as the differing conditions among countries necessitate different approaches to health sensitivity and impact assessments, so too will the approaches to adaptation differ by region. For many developing countries, the health problems that are likely to be exacerbated by climate change are significant. Thus, adaptive strategies developed in anticipation of future climate conditions may have substantial utility for the present situation. The include:

- (1) Ongoing surveillance, both of human disease and critical ecosystem indicators, will be essential to the timely institutionalization of interventions as disease systems change. Surveillance should include intermediate indicators such as vector populations and vegetation as well as actual disease incidence. A strategy for global monitoring of health effects of climate change has been proposed involving remote sensing and extensive telecommunications networks of environmental and health professionals. Such an effort is strongly needed on a global scale, but smaller efforts on a regional scale, targeted at the critical geographic areas identified in the sensitivity analysis, will be important for regional adaptation strategies as well.
- (2) Investment in and expansion of water treatment facilities that may be further threatened by severe storms and sea level rise due to climate change.
- (3) Education and promotion of appropriate human behavior such as the proper storage of open water containers, proper disposal of human wastes, appropriate types of clothing worn and the filtering of drinking water. Public education efforts will be needed, both to inform about

the causes of disease and human impacts on disease, as well as to instruct on ways to minimize the health impacts of climate change.

- (4) Education and involvement of diverse groups of people and local communities in regional adaptation efforts.

In addition to the general adaptive strategies discussed above, the following variety of impact-specific options is available.

- Maintaining disaster preparedness programs, including tools for local public health facilities to conduct rapid health needs assessments.
- Engineering measures such as strengthening sea-walls or requiring building contractors to follow hurricane standards in coastal areas.
- Adopting landuse planning to minimize erosion, flash, precarious residential placements.
- Siting intakes for water facilities far enough upstream to tolerate saline intrusion from storm surges and sea level rise.
- Installing window screens in areas endemic to insect-borne diseases.
- Expanding coverage of vaccination programs in critical areas aimed at infectious diseases that are likely to increase with climate change, e.g., yellow fever (unfortunately, no vaccines exist as yet for some sensitive diseases such as malaria and dengue).
- Public education to encourage elimination of manmade breeding sites (i.e., small water containers for aede's mosquitoes).
- Education campaigns to sensitize health care givers in geographically vulnerable regions.
- Release of sterilized male insects to reduce reproductive capacity of vector populations.
- Promoting the use of pyrethroid impregnated mosquito bed-nets.
- Possibly creating early warning systems based on algal blooms to predict cholera.
- Public education on sources of infection.
- Distribution of low-technology water filtration systems (i.e., nylon mesh, cloths).
- Designing building to be more heat resistant (insulation, air flow).
- Planting trees within cities to reduce the urban heat-island effect.
- Establishing new weather watch/warning systems that focus on health-related adverse conditions, such as oppressive air masses.
- Creating education campaigns regarding precautions to take during heat waves.
- Work schedules that avoid peak temperatures for outdoor laborers.
- Producing climate-resistant transgenic plants (genetically engineered).
- Reducing the proportion of monocultural for better crop resistance to pest.

- Promoting land reforms that would favor environmentally sound land usage.

When considered in total, these adaptive measures will offer varying amounts of protection to human health. Critical evaluation of implemented strategies will be needed to inform a dynamic process of adaptation.

#### **3.6.4. Data Requirement**

For the baseline assessment:

- Principal causes of mortality by age group.
- Principal infectious diseases with incidence/prevalence data arranged by age group and geographic distribution.
- Populations living at low elevations in coastal zones, populations with poor or marginal drinking water quality, arranged by geographic distribution.
- Prevalence of malnutrition, arranged by age group and geographic distribution.
- General demographic data on income, education, geographically arranged, with population growth predictions
- Any available GCM predictions for the country or regions within the country
- Any existing historical analogue studies in a given country should be reviewed and included in the baseline assessment.

For mapping/GIS studies:

- Current climate data, including minimum and maximum seasonal temperatures, precipitation levels, average monthly temperatures, by smallest geographical and political possible.
- Predicted changes in above climate data from available GCM models. If such data are lacking, arbitrary changes encompassing the range of possible changes can be substituted.
- For infectious diseases, it may be useful to map vegetation types to assess suitability and continuity of habitats for vector species. This data may be obtainable from other sectors (grasslands, agriculture, coastal resources, etc.)

- Also, for infectious disease, information on surface water irrigation and other means of water distribution is useful.

For GIS and remote sensing:

- Geographic data arranged in a suitable format(raster or vector).
- Data from baseline assessment arranged in the same GIS format.
- Geographic (including land-use), ocean (including temperature and plankton populations) and vegetation data may be obtained from satellite images, allowing relatively easy updating for future analyses.

For TARGETS:

- Population and food intake data.
- GNP and governmental health investment levels.
- Climate data; baseline (preferably 1951-1980) available from local weather stations; and projections, either from GCM models or using a range of arbitrary changes.
- Baseline disease incidence/prevalence data.

### **3.7: COASTAL RESOURCES IMPACT AND ADAPTATION ASSESSMENTS**

#### ***3.7.1: Assessment Methodology:***

The impact assessment procedure used follows the Aerial Videotape-assisted Vulnerability Analysis (AVVA) technique and the IPCC Common Methodology. AVVA is a new, rapid and low-cost technique, which involves the combination of:

- (1) obliquely videotaping the coastline at low altitude from a small airplane, and
- (2) archival research.

Combining the video record and the historical data, it was possible to assess, both qualitatively and quantitatively, some of the potential impacts of 1 metre sea level rise. The assessment involves the following steps.

- (1) characterization of the study area,
- (2) determination of sea level scenarios,
- (3) estimation of land loss and other damages,
- (4) translation of these damages to monetary terms, and
- (5) identification of response strategies and adaptation options.

Based on the assembled data it is possible to characterize the coastal zone of the country into the different units with each unit containing one or a combination of coastal types.

Tide gauge records available for the study area and long-term geological data could be used to assess the sea level scenarios to be used in the assessment. Where these are lacking or inadequate the global sea level rise scenarios that have been widely adopted in the IPCC documentation can be used. These scenarios are the current rate of sea level rise of 0.2 metre per century (no acceleration), 0.5 metre per century, and 1.0 metre per century. Where the variation of the land formation is relatively smooth, the 0.5-metre contour of land inundation can be interpolated from the 1.0-metre contour line on the coastal map series.

Of primary concern is to determine how much land will be lost due to sea level rise. In the sheltered coasts and where the open coast is characterized by spits/barriers backed by marshes and mangroves and, in some places, strand plain type coast, the drowning or permanent submergence (inundation) concept of land lost could be used as the initial potential impact. After inundation, erosion of the open coast continues due to wave action and the Bruun Rule could be used to determine retreat of the land.

The area likely to be inundated is delineated on the topographic maps by estimating the 1-metre contour line. Land loss due to the lower scenarios is estimated by linear interpolation from the amount of loss due to the one-metre sea level rise. The percentage loss for intermediate scenarios (0.5 m) is then linearly interpolated.

Land loss due to erosion is estimated using the mathematical definition of the Bruun rule as:

$$\mathbf{R} = \mathbf{G}(\mathbf{L}/(\mathbf{B}+\mathbf{d}_*))\mathbf{S}$$

where, **R** is the shoreline retreat (erosion) due to a sea-level rise **S** (scenario) above mean sea level, **d\*** is the depth of closure, **B** is the dune/cliff height, **L** is the width of the active profile, and **G** is the inverse of the overfill ratio of the material being eroded. The overfill ratio, **G**, can be safely taken to be 1 where sand is predominant in the coast type because it is assumed that all the eroded material will remain within the active beach/near shore profile. Where this assumption is not valid, meaning some of the eroded material is lost to deeper water because it is fine-grained (clay and silt), greater recession would be expected.

The current depth of closure, **h\***, is determined using a range of techniques which include grain size trends, the orientation of offshore contours and wave-based approach. According to Nicholls et al (1995), it is best to use the wave-based approach, as this can be directly related to time scale. Various studies conducted so far on the estimation the potential impacts of sea level rise used the low and high estimates of closure depth, which will embrace the actual depth of closure. The depth of closure for the 100-year period is calculated from the annual depth of closure as:

$$\mathbf{h}_{*(\mathbf{L},100)} = 1.75 \mathbf{h}_{*(\mathbf{L},1)}$$

where the coefficient (1.75) is based on Hands (1977, 1983).

The low and active profile widths (**L**) were determined at different locations along the coast using bathymetric maps.

### ***Flooding and Increase in Ground Water Levels.***

Projections are that, the strength and frequency of tropical storms are expected to increase with the expected climate change. This will lead to more flooding, and the problem may be exacerbated with sea level rise. Damage to structures such as buildings and roads will be the major effect of the fresh water flooding. However, flooding of groundwater resources with salt water is possible in those areas that are close to salt marches and wetlands and settlements close

to these areas and those established on reclaimed land in dried up valleys. These are also the main areas where ground water levels are high enough and saline intrusion in groundwater could already be a problem.

### ***Estimation of Value of Damage and Population at Risk.***

A comprehensive evaluation of the economic consequence of a one-metre sea level rise for the study area should be conducted where there is adequate data and resources. The value and costs of damage or loss to coastal infrastructure, such as roads, should be evaluated. A qualitative assessment of wetlands could be possible and should be conducted as these are not valued in monetary terms.

#### ***3.7.2: Data Requirements***

Various data sets on the coastal zone need to be assembled to inventorize and characterize the study areas. The data and information should include black and white, and colour infrared aerial photographs; and topographic, geological and bathymetric maps of the study area. These could be acquired from archives or purchased from the Department of Lands and Surveys of the country. Where available contoured orthophoto maps of the aerial photography for the country should be used. Multi-year and multi-location still photographs of the coastal zone showing some of the damage caused by erosion should be made available to the Assessment Team.

A low-level (~ 150 to 200 metres) video record of both the open and sheltered coasts of the country is required and could be obtained as part of the Aerial Videotape assisted Vulnerability Analysis (AVVA) technique (Leatherman et al 1995). From the video record it is possible to determine the type of coast, land-use, land cover and infrastructure.

Socio-economic data (GDP, GNP, etc), annual number of tourists and out-of-pocket expenditure, information on fish landing and catch by species, wetland habitats, and historic and cultural assets need to be collected.

### **3.8: INTEGRATION APPROACHES**

#### ***3.8.1: Integration across Sectors***

Is designed to deal with the interactions across sectors, a change in one sector (resulting from climate change impacts) can have on another sector. For example, altering water resources because of climate changes could impact agricultural productivity independently of the direct effects of climatic changes on the agricultural sector, in low-lying coastal agricultural regions, sea-level rise threatens to allow saltwater to find its way into fresh water supplies used to water crops.

With these types of cross-sector effects, the integration effort is designed primarily to ensure a consistent result for all sectors, if the agricultural sector increased its use of irrigation as an adaptive measure. Such an increase in use would depend on the availability of adequate water supplies under climate change scenarios. Agricultural demand would have to compete with demands from urban and commercial users, thus requiring coordinated regional planning and management strategies, changes in climatic conditions may create economic incentives for displacing grazing systems with cropping systems, thereby shifting grazing to more marginal areas. Conversely, adapting to climate change may necessitate abandonment of farmland with land left to revert to natural vegetation and rangelands.

#### ***3.8.2: Integration using economic Costs***

Using economic costs to evaluate a country's climate change vulnerability and adaptation options is a very effective integration analysis techniques in cases where sufficient economic data exist. Costs used in this analysis should be developed by means of standard economic analysis and accounting procedures, costs should be expressed in terms of net present value. Discount rates should be those used by the country in the analysis of development projects. Cost figures should include both expenses and revenues associated with the sectoral impact.

The cost figures from each of the sectors can be combined in several ways. The simplest way is to develop a total cost to the country of climate change, including damage costs (e.g. value of land lost to sea level rise) and revenue increases (e.g. increased crop yields due to warmer temperatures). Analysis of adaptation options can be presented in terms of either a cost

effectiveness analysis (e.g. what is the cost of an adaptation techniques per unit of decrease in damage) or a cost-benefit analysis (e.g. the comparison of total costs with total benefits).

By using a common metric of economic costs, it will be possible to compare the results from different sectors on a consistent basis. It will also be possible to determine the economic viability of alternative strategies for adapting to climate change impacts. However, the development of cost figures for the impacts in each sector may, in practice, be very difficult because some impacts are not easily expressed in terms of economic cost.

### ***3.8.3: Populations Affected***

Often the most important impact from a policy and/or societal preparative is that related to the extent of human populations affected by a given phenomenon. For example, sea level rise declines in agricultural productivity, reduction in available water, and deterioration of air quality due to climate change can all be integrated in terms of the number of people impacted by these changes.

### ***3.8.4: Land Use***

In many cases, impacts of climate changes on various sectors and/or components of a given sector cannot be expressed in economic terms. In some of these cases, land use can be disrupted to integrate impacts across such sectors/components, impacts to croplands, forest, coastal area and grasslands may best be evaluated in terms of the quantity of land disrupted, it may not be possible to place an economic value on the impacts of climate change on some individual components of a given sector such as destruction or deterioration of wildlife habitat because of changes in forest composition or drying up of wetlands or marshes. In such cases, quantity of land disrupted or altered can be used to integrate impacts.

In addition to the quantitative metrics, qualitative metrics can also be used; impacts to each sector can be characterized as extensive, moderate, or minimal. The result is a qualitative identification of which sectors are likely to experience the most severe impacts from climate change.

One of the problems in using qualitative measures is the difficulty in developing an overall evaluation. An approach to dealing with this problem is to use multi-attribute decision analysis. This technique combines items that are measured by different metrics, including both quantitative and qualitative into an integrated picture. The decision analysis techniques have been used in many other areas but not to date in climate change vulnerability and adaptation studies.

All of these approaches serve similar purposes-to support aggregation of impacts across sectors to facilitate comparisons between alternative adaptive strategies, and to weigh the relative merits of different response.

### ***3.8.5: Integration with Other Government Programs***

If possible, the results of the biophysical impact assessments should be factored into the general natural resource management plans and policies and into future research programs being planned by the government. There may be important interactions and implications for these other programs and for climate change vulnerability and adaptation.

