Global Chapter 5   APPENDIX: Model descriptions

A.5.1   The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)

A.5.1.1 Introduction

IMPACT was developed in the early 1990s as a response to concerns about a lack of vision and consensus regarding the actions required to feed the world in the future, reduce poverty, and protect the natural resource base (Rosegrant et al., 1995). In 2002, the model was expanded through inclusion of a Water Simulation Model (WSM) as water was perceived as one of the major constraints to future food production and human well-being (Rosegrant et al., 2002).

A.5.1.2 Model structure and data

The current IMPACT model combines an extension of the original model with a WSM that is based on state-of-the-art global water databases (Rosegrant et al., 2002). The water module projects the evolution of availability and demand with a base year of 2000 (average of 1999-2001), taking into account the availability and variability in water resources, the water supply infrastructure, and irrigation and nonagricultural water demands, as well as the impact of alternative water policies and investments. Water demands are simulated as functions of year-to-year hydrologic fluctuations, irrigation development, growth of industrial and domestic water uses, and environmental and other flow requirements (committed flow). Off-stream water supply for the domestic, industrial, livestock, and irrigation sectors is determined based on water allocation priorities, treating irrigation water as a residual. Environmental flows are included as constraints.

The food module is specified as a set of 115 country or regional sub-models. Within each sub-model, supply, demand and prices for agricultural commodities are determined for 32 crop, livestock, and fish commodities and fishmeal, sugar and sweeteners, fruits and vegetables, and low value and high value fish. These country and regional sub-models are intersected with 126 river basins—to allow for a better representation of water supply and demand—generating results for 281 Food Producing Units (FPUs). The "food" side of IMPACT uses a system of food supply and demand elasticities incorporated into a series of linear and nonlinear equations, to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Demand is a function of prices, income and population growth. Growth in crop production in each country is determined by crop prices and the rate of productivity growth. Future productivity growth is estimated by its component sources, including crop management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private sector agricultural research and development, agricultural

extension and education, markets, infrastructure and irrigation. IMPACT projects the share and number of malnourished preschool children in developing countries as a function of average per capita calorie availability, the share of females with secondary schooling, the ratio of female to male life expectancy at birth, and the percentage of the population with access to safe water (see also Rosegrant et al., 2001; Smith and Haddad, 2000). The model incorporates data from FAOSTAT (FAO, 2003); commodity, income, and population data and projections from the World Bank (2000), the Millennium Ecosystem Assessment (2005), and the UN (2000) and USDA (2000); a system of supply and demand elasticities from literature reviews and expert estimates (Rosegrant et al., 2001); and rates for malnutrition (UN ACC/SCN, 1996; WHO, 1997) and calorie-child malnutrition relationships developed by Smith and Haddad (2000).

A.5.1.3 Application

IMPACT has been used for analyzing the current and future roles of agricultural commodities and impacts on food security and rural livelihoods, including the future of fisheries (Delgado et al., 2003); the role of root and tuber crops (Scott et al. 2000a, 2000b); and the 'livestock revolution' (Delgado et al., 1999). IMPACT has also been applied to regional analyses as well as selected country-level studies, for example, China (Huang et al., 1997), Indonesia (SEARCA/IFPRI/CRESECENT 2004), Sub-Saharan Africa (Rosegrant et al., 2005a) and Central Asia (Pandya-Lorch and Rosegrant, 2000). IMPACT has also been used to analyze structural changes, including the impact of the Asian economic and financial crisis (Rosegrant and Ringler, 2000); longer-term structural changes in rural Asia (Rosegrant and Hazell, 2000); as well as global dietary changes (Rosegrant et al., 1999). The model has also been used to describe the role of agriculture and water for achieving the Millennium Development Goals (von Braun et al., 2004; Rosegrant et al., 2005b).

Model runs have been carried out for individual centers of the CGIAR, the World Bank and the Asian Development Bank. The model has also been used for agricultural scenario analysis of the Millennium Ecosystem Assessment (Alcamo et al., 2005; MA, 2005), and is currently being used for the Global Environmental Outlook (GEO-4) assessment carried out by UNEP. Other work includes investigations into regional and global scale impacts of greenhouse gas mitigation in agriculture and theoretical large-scale conversion to organic food production.

A.5.1.4 Uncertainty

In the following tables, the points related to uncertainty in the model are summarized, based on the level of agreement and amount of evidence.

Table A.5.1 Overview of major uncertainties in IMPACT

Model Component	Uncertainty
Model structure	• Based on partial equilibrium theory (equilibrium between demand and supply of all commodities and production factors) • Underlying sources of growth in area/numbers and productivity • Structure of supply and demand functions and underlying elasticities, complementary and substitution of factor inputs. • Water simulations and connection between Water and Food modules
Parameters	Input parameters: • Base year, 3-year centered moving averages for area, yield, production, numbers for 32 agricultural commodities and 115 countries and regions, and 281 Food Producing Units • Elasticities underlying the country and regional demand and supply functions • Commodity prices • Drivers Output parameters: • Annual levels of water supply and demand (withdrawals and depletion), both agricultural and nonagricultural, food supply, demand, trade, international food prices, calorie availability, and share and number of malnourished children
Driving Force	Economic and demographic drivers: • Income growth (GDP) • Population growth Technological, management, and infrastructural drivers: • Productivity growth (including management research, conventional plant breeding) for rainfed and irrigated areas • Rainfed and irrigated area growth • Livestock feed ratios • Changes in nonagricultural water demand • Supply and demand elasticity systems Policy drivers: • Commodity price policy as defined by taxes and subsidies on commodities, drivers affecting child malnutrition, food demand preferences, water infrastructure, etc.
Initial Condition	• Baseline – 3-year average centered on 2000 of all input parameters and assumptions for driving forces
Model operation	• Optimization in Water Simulation Model using GAMS

Source: Based on (MA, 2005)

Table A.5.2 Level of confidence in different types of scenario calculations from IMPACT

Level of Agreement/ Assessment			
	High	Established but incomplete: • Projections of Rainfed Area, Yield • Projections of Irrigated Area, Yield, • Projections of Livestock Numbers, Production • Number of Malnourished Children • Calorie availability • Climate variability	Well established: • Changes in Consumption Patterns and Food Demand
	Low	Speculative:	Competing explanations: • Projections of Commodity Prices • Commodity Trade • Climate change
		Low	High
		Amount of evidence (theory, observations, model outputs)	

Source: Based on (MA, 2005)

A.5.2 The Integrated Model to Assess the Global Environment (IMAGE) 2.4

A.5.2.1 Introduction

The IMAGE modelling framework had been developed originally to study the causes and impacts of climate change within an integrated context. Now the IMAGE 2.4 is used to study a whole

range of environmental and global change problems, in particular aspects of land use change, atmospheric pollution and climate change. The model and its submodels have been described in detail in several publications (Alcamo et al. 1998; IMAGE team 2001; Bouwman et al., 2006).

A.5.2.2 Model structure and data

The IMAGE 2.4 framework describes global environmental change in terms of its cause-response chain, and belongs to the model family of integrated assessment models. The IMAGE model consists of two major parts: the socioeconomic system, elaborating on future changes in demographics, economy, agriculture and the energy sector, and the biophysical system, comprising land cover and land use, atmospheric composition and climate change. The IMAGE model focuses on linking those two parts through emissions and land allocation. Land allocation follows inputs from the IMPACT model, allowing an assessment of the environmental consequences of changes in the agricultural sector. One of the crucial parts of the IMAGE 2.4 model is the energy model, Targets IMage Energy Regional (TIMER). The TIMER model describes the chain, going from demand for energy services (useful energy) to the supply of energy itself through different primary energy sources and related emissions. The steps are connected by demand for energy and by feedbacks, mainly in the form of energy prices. The TIMER model has three types of sub-models: (i) a model for energy demand,; (ii) models for energy conversion (electricity and hydrogen production) and (iii) models for primary energy supply. The final energy demand (for five sectors and eight energy carriers) is modelled as a function of changes in population, economic activity and energy efficiency. The model for electricity production simulates investments in various electricity production technologies and their use in response to electricity demand and to changes in relative generation costs.

Supply of all primary energy carriers is based on the interplay between resource depletion and technology development. Technology development is introduced either as learning curves (for most fuels and renewable options) or by exogenous technology change assumptions (for thermal power plants). To model resource depletion of fossil fuels and uranium, several resource categories that are depleted in order of their costs are defined. Production costs thus rise as each subsequent category is exploited. For renewable energy options, the production costs depend on the ratio between actual production levels and the maximum production level. Climate change mitigation policies can be implemented in the TIMER model, allowing assessing changes in the energy composition due to these policies (Van Vuuren et al., 2006; Van Vuuren et al., 2007).

The TIMER model also simulates the potential importance of biomass as an energy category. The structure of the biomass sub-model is similar to that of the fossil fuel supply models but with a few important differences (see also Hoogwijk et al., 2005). First, in the bioenergy model,

depletion is not governed by cumulative production but by the degree to which available land is being used for commercial energy crops. Available land is defined as abandoned agricultural land and part of the natural grasslands in divergent land use variants for the twenty-first century and is based on IMAGE alternative variant calculations. This assumption excludes any possible competition between bioenergy and food production, which is a simplification of reality. The potential available land is categorized according to productivity levels that are assumed to reflect the cost of producing primary biomass. The biomass model also describes the conversion of biomass (such as residues, wood crops, maize and sugar cane) to two generic secondary fuel types: biosolid fuels (BSF) and bioliquid fuels (BLF). The solid fuel is used in the industry and power sector, and the liquid fuel in other sectors, in particular, transport.

The output of TIMER is affecting the biophysical system of IMAGE through land use changes (for bioenergy) and emissions (from the energy sector). Changes in food production are taken from IMPACT. The land cover model of IMAGE simulates the change in land use and land cover in each region driven by demands for food, including crops, feed, and grass for animal agriculture, timber and biofuels in addition to changes in climate (Bouwman et al., 2005; Eickhout et al., 2007). The model distinguishes 14 natural and forest land cover types and six land cover types created by people. A crop module based on the FAO agroecological zones approach computes the spatially explicit yields of the different crop groups and grass and the areas used for their production, as determined by climate and soil quality (Alcamo et al., 1998). In case expansion of agricultural land is required, a rule-based "suitability map" determines which grid cells are selected. Conditions that enhance the suitability of a grid cell for agricultural expansion include potential crop yield (which changes over time as a result of climate change and technology development), proximity to other agricultural areas and proximity to water bodies. The land cover model also includes a modified version of the BIOME model (Prentice et al., 1992) to compute changes in potential vegetation. The potential vegetation is the equilibrium vegetation that should eventually develop under a given climate. The shifts in vegetation zones, however, do not occur instantaneously. In IMAGE 2.4 such dynamic adaptation is modelled explicitly according to the algorithms developed by Van Minnen et al. (2000). This allows for assessing the consequences of climate change for natural vegetation (Leemans and Eickhout, 2004).The land use system is modelled on a 0.5 by 0.5 degree grid.

Both changes in energy consumption and land use patterns give rise to emissions that are used to calculate changes in atmospheric concentration of greenhouse gases and some atmospheric pollutants such as nitrogen- and sulphur oxides (Strengers et al., 2004). Changes in concentration of greenhouse gases, ozone precursors and species involved in aerosol formation form the basis for calculating climatic change (Eickhout et al., 2004). Next, changes in climate are

calculated as global mean changes which are downscaled to the 0.5 by 0.5 degree grids using patterns generated by a General Circulation Model (GCM). Through this approach, different GCM patterns can be used to downscale the global-mean temperature change, allowing for the assessment of uncertainties in regional climate change (Eickhout et al., 2004). An important aspect of IMAGE is that it accounts for crucial feedbacks within the system, such as among temperature, precipitation and atmospheric CO_2 on the selection of crop types and the migration of ecosystems. This allows for calculating changes in crop and grass yields and as a consequence the location of different types of agriculture, changes in net primary productivity and migration of natural ecosystems (Leemans et al., 2002).

A.5.2.3 Application

The IMAGE model has been applied to a variety of global studies. The specific issues and questions addressed in these studies have inspired the introduction of new model features and capabilities, and in turn, the model enhancements and extensions have broadened the range of applications that IMAGE can address. Since the publication of IMAGE 2.1 (Alcamo et al. 1998), subsequent versions and intermediate releases have been used in most of the major global assessment studies and other international analyses, like the IPCC Special Report on Emissions Scenarios (Nakicenovic et al., 2000), UNEP's Third and Fourth Global Environment Outlook (UNEP, 2002; 2007), The Millennium Ecosystem Assessment (MA, 2006), the Second Global Biodiversity Outlook (SCBD/MNP, 2007) and Global Nutrients from Watersheds (Seitzinger et al., 2005).

A.5.2.4 Uncertainty

As a global Integrated Assessment model, the focus of IMAGE is on large scale, mostly first order drivers of global environmental change. This obviously introduces some important limitations to its results, and in particular the interpretation of its accuracy and uncertainty. An important method for handling some of the uncertainties is by using a scenario approach. A large number of relationships and model drivers that are either currently not known or depend on human decisions are varied in these scenarios, to explore the uncertainties involved in them (see IMAGE Team, 2001). In 2001 a separate project was performed to evaluate the uncertainties in the energy model using both quantitative and qualitative techniques. With this analysis the model's most important uncertainties were seen to be linked to its assumptions for technological improvement in the energy system, and how human activities are translated into a demand for energy (including human lifestyles, economic sector change and energy efficiency, seen in Table A.5.3).

Table A.5.3 Overview of major uncertainties in IMAGE 2.4

Model component	Uncertainty
Model structure	• TIMER Energy model: Integration in larger economy and dynamic formulation in

	energy model (learning by doing)
	• Land model: Rule-based algorithm for allocating land use
	• Environmental system: Scheme for allocating carbon pools in the carbon cycle model
Parameters	• Energy: Resource assumption and learning parameters
	• Land: Biome model parameter setting and CO2 fertilization
	• Environment: Climate sensitivity, climate change patterns and multipliers in climate model (Leemans et al., 2002)
Driving force	• Income growth (GDP)
	• Population growth
	• Assumptions on technology change in energy model
	• Environmental policies
Initial condition	• Emissions in base year (2000)
	• Historic energy use
	• Initial land use/land cover map
	• Historical land use data (from FAO)
	• Climate observations in initial year
Model operation	• Downscaling method in climate change model (Eickhout et al., 2004)

The carbon cycle model has also recently been used for a sensitivity analysis to assess uncertainties in carbon cycle modeling in general (Leemans et al., 2002). Finally, a main uncertainty in IMAGE's climate model has to do with (1) "climate sensitivity," i.e., the response of global temperature computed by the model to changes in atmospheric greenhouse gas concentrations, and (2) regional patterns of changed temperature and precipitation. IMAGE 2.2 has actually been set up in such a way that these variables can be easily manipulated on the basis of more scientifically-detailed models. To summarize most of IMAGE would need to go into the category of established but incomplete knowledge (Table A.5.4).

Table A.5.4 Level of confidence in different types of scenario calculations from IMAGE

		Established but incomplete • Climate impacts on agriculture and biomes • Carbon cycle	Well established • Energy modeling and scenarios
Level of Agreement/ Assessment	High		
	Low	Speculative • Grid-level changes in driving forces • Impacts of land degradation	Competing explanations • Global climate change, including estimates of uncertainty • Local climate change • Land use change
		Low	High
		Amount of evidence (theory, observations, model outputs)	

A.5.3   The Global Trade and Environment Model (GTEM)

A.5.3.1 Introduction

GTEM has been developed by the Australian Bureau of Agricultural and Resource Economics (ABARE) specifically to address policy issues with global dimensions and issues where the interactions between sectors and between economies are significant. These include issues such as international climate change policy, international trade and investment liberalisation and trends in global energy markets.

A.5.3.2 Model structure and data

GTEM is a multiregion, multisector, dynamic, general equilibrium model of the global economy. The key structural features of GTEM include:

• A computable general equilibrium (CGE) framework with a sound theoretical foundation based on microeconomic principles that accounts for economic transactions occurring in the global economy. The theoretical structure of the model is based on the optimizing behavior of individual economic agents (e.g., firms and households), as represented by the model equation systems, the database and parameters.

• A recursively dynamic analytical framework characterized by capital and debt accumulation and endogenous population growth, which enables the model to account for transactions between sectors and trade flows between regions over time. As a dynamic model, it accounts for the impacts of changes in labor force and investment on a region's production capabilities.

• The representation of a large number of economies (up to 87 regional economies corresponding to individual countries or country groups) that are linked through trade and investment flows, allowing for detailed analysis of the direct as well as flow-on impacts of policy and exogenous changes for individual economies. The model tracks intraindustry trade flows as well as bilateral trade flows, allowing for detailed trade policy analysis.

• A high level of sectoral disaggregation (up to 67 broad sectors, with an explicit representation of 13 agricultural sectors) that helps to minimize likely biases that may arise from an undue aggregation scheme.

- A bottom-up "technology bundle" approach adopted in modeling energy intensive sectors, as well as interfuel, interfactor and factor-fuel substitution possibilities allowed in modeling the production of commodities. The detailed and explicit treatment of the energy and energy related sectors makes GTEM an ideal tool for analysing trends and policies affecting the energy sector.

- A demographic module that determines the evolution of a region's population (and hence, the labor supply) as a function of fertility, migration and mortality, all distinguished by age group and/or gender.

- A detailed greenhouse gas emissions module that accounts for the major gases and sources, incorporates various climate change response policies, including international emissions trading and quota banking, and allows for technology substitution and uptake of backstop technologies.

For each regional economy, the GTEM database consists of six broad components: the input–output flows; bilateral trade flows; elasticities and parameters; population data; technology data; and anthropogenic greenhouse gas emissions data. For the input–output and bilateral trade flows data, and the key elasticities and parameters, the GTAP version 6 database (see https://www.gtap.agecon.purdue.edu/databases/v6/default.asp) has been adapted. The databases for population, energy technology and anthropogenic greenhouse gas emissions, have been assembled by ABARE according to GTEM regions using information from a range of national and international sources. The base-year for GTEM is 2001. For this exercise, the model database has been aggregated to 21 regions that correspond to the five IAASTD sub-global regions and to 36 commodities that include 12 agricultural sectors and one fisheries sector.

GTEM equations are written in log-change forms and the model is solved recursively using the GEMPACK suite of programs (http://www.monash.edu.au/policy/gempack.htm). For IAASTD modeling purposes, the GTEM projection period expends to 2050. The model simulation provides annual projections for many variables including regional gross national product, aggregate consumption, investment, exports and imports; sectoral production, employment and other input demands; final demand and trade for commodities; and greenhouse gas emissions by gas and by source.

A detailed description of the theoretical structure of GTEM can be found in Pant (2002, 2007). Pezzey and Lambie (2001) describe the key structural features of GTEM and Ahammad and Mi (2005) discuss an update on the modeling of GTEM agricultural and forestry sectors.

A.5.3.3 Application

GTEM has been applied to a wide range of medium- to long-term policy issues or special events. These include climate change response policy analysis (e.g., Ahammad et al., 2006; Ahammad et al., 2004; Fisher et al., 2003; Heyhoe, 2007; Jakeman et al., 2002; Jakeman et al., 2004; Jotzo, 2000; Matysek et al., 2005; Polidano et al., 2000; Tulpulé et al., 1999); global energy market analysis (e.g., Ball et al., 2003, Fairhead et al., 2002; Heaney et al., 2005; Mélanie et al., 2002; Stuart et al., 2000); and on agricultural trade liberalisation issues (e.g., Bull and Roberts 2001; Fairhead and Ahammad, 2005; Freeman et al., 2000; Nair et al., 2005; Nair et al., 2006; Roberts et al., 1999; Schneider et al., 2000).

A.5.3.4 Uncertainty

Table A.5.3.4 Uncertainty

Model component	Uncertainty
Model structure	• Based on general equilibrium theory. • Conforms to a competitive market equilibrium—no 'supernormal' economic profit. • Structured on nested supply and demand functions representing technologies, tastes, endowments and policies. • Incorporates the Armington demand structure—a commodity produced in one region treated as an imperfect substitute for a similar good produced elsewhere. • Total demand equals total supply—for all commodities at the global level and for production factors at the regional level.
Parameters	Input parameters: • Base year input-output flows and (bilateral) trade flows for 67 commodities and 87 countries and regions. • Numerous elasticities underlying demand and supply equations. • Technical coefficients for anthropogenic greenhouse gas emissions.
Driving Force	• Regional income growth (GDP). • Population growth. • Changes in policies (taxes and subsidies). • Technological changes—productivity growth and energy technology options. The choice of the model closure, i.e., the distinction between exogenous (drivers or shocks) and endogenous (determined or projected) variables of the model, is quite flexible. The above variables, e.g., could also be determined endogenously within the model for some specific economic closure characterized by a well specified set of economic and demographic shocks.
Initial Condition	• The 2001 global economy in terms of production, consumption and trade.
Model operation	• Suite of GEMPACK programs.

A.5.4. WATERSIM

A.5.4.1 Introduction

Watersim is an integrated hydrologic and economic model, written in GAMS, developed by IWMI with input from IFPRI and the University of Illinois. It seeks to:

- explore the key linkages between water, food security, and environment.

- develop scenarios for exploring key questions for food water, food, and environmental security, at the global national and basin scale

A.5.4.2 Model structure and data

The general model structure consists of two integrated modules: the "food demand and supply" module, adapted from IMPACT (Rosegrant et al., 2002), and the "water supply and demand" module which uses a water balance based on the Water Accounting framework (Molden, 1997) that underlies the policy dialogue model, PODIUM combined with elements from IMPACT (Cai and Rosegrant, 2002). The model estimates food demand as a function of population, income and food prices. Crop production depends on economic variables such as crop prices, inputs and subsidies on one hand, and climate, crop technology, production mode (rainfed or. irrigated) and water availability on the other. Irrigation water demand is a function of the food production requirement and management practices, but constrained by the amount of available water.

Water demand for irrigation, domestic purposes, industrial sectors, livestock and the environment are estimated at basin scale. Water supply for each basin is expressed as a function of climate, hydrology and infrastructure. At basin level, hydrologic components (water supply, usage and outflow) must balance. At the global level, food demand and supply are leveled out by international trade and changes in commodity stocks. The model iterates between basin, region and globe until the conditions of economic equilibrium and hydrologic water balance are met.

Different aspects of the model use different spatial units. To model hydrology adequately, the river basin is used as the basic spatial unit. For food policy analysis, administrative boundaries should be used since trade and policy making happens at national level, not at the scale of river basins. WATERSIM takes a hybrid approach to its spatial unit of modeling. First, the world is divided into 125 major river basins of various sizes with the goal of achieving accuracy with regard to the basins most important to irrigated agriculture. Next the world is divided into 115 economic regions comprised of mostly single nations with a few regional groupings. Finally the river basins are intersected with the economic regions to produce 282 Food Producing Units (FPUs). The hydrological processes are modeled at basin scale by summing up relevant parameters and variables over the FPUs within one basin; similarly economic processes are modeled at regional scale by summing up the variables over the FPUs belonging to one region.

The model uses a temporal scale with a baseline year of 2000. Economic processes are modeled at an annual time-step, while hydrological and climate variables are modeled at a monthly time-step. Crop related variables are either determined by month (crop evapotranspiration) or by season (yield, area). The food supply and demand module runs at region level on a yearly time-step. Water supply and demand runs at FPU level at a monthly time-step. For the area and yield computations the relevant parameters and variables are summed over the months of the growing season.

A.5.4.3 Application

Watersim has been used in the following cases:

- Scenario analysis in the Comprehensive Assessment of Water Management in Agriculture (CA, 2007)

- Sub-Saharan Africa investment study

- ICID – India Country paper

- Scenarios at basin level for the benchmark basins in the Challenge Program on Water and Food

A.5.4.4 Uncertainty

The water and food modules are calibrated at the base year 2000 and 1995. Model outcomes aggregated at a relatively high level (globe, continent, major basins such as the Indo-Gangetic) tend to have a better agreement than outcomes at sub-basin level. This reflects the uncertainty associated with global datasets, shown in Table A.5.6.

Table A.5.6 Overview of major uncertainties in Watersim model

Model Component	Uncertainty
Model Structure	Food module is based on IMPACT (well established). Water module borrows from Podium, IMPACT and Water accounting methodology (all well established)
Parameters	Input: see list below Output: projections on water demand by basin (128) and country (115), water scarcity indices, production coming from irrigated and rainfed areas, crop water use, water productivity and basin efficiency
Driving force	• population and GDP growth • crop demand • improvements in water productivity • improvements in basin efficiency
Initial condition	Parameters are calibrated to the base year (2000). Based on the best available data sources, uncertainty minimized as far as possible, but in particular water use efficiency data are sketchy in developing countries
Model operation	Runs in GAMS

Table A.5.7 Level of confidence for scenario calculations with Watersim model

Level of Agreement/ Assessment	High	Established but incomplete: • Areas suffering from water scarcity • Virtual water flows due to food trade	Well-established: Global estimates and projections of crop water use
	Low	Speculative: • Crop losses due to water shortages • Impacts of environmental flow policies on food production	Competing Explanations: • Projections of irrigated areas and production • Projections of rainfed areas and production • Projections of irrigation water demand • Projections of water productivity
		Low	High
		Amount of Evidence (Theory, Observations, Model Outputs)	

A.5.5 CAPSiM

A.5.5.1 Introduction

China's Agricultural Policy Simulation and Projection Model (CAPSiM) was developed at the Center for Chinese Agricultural Policy (CCAP) in the mid-1990s as a response to the need to have a framework for analyzing policies affecting agricultural production, consumption, prices, and trade in China (Huang et al., 1999; Huang and Chen, 1999). Since then CAPSiM has been periodically updated and expanded at CCAP to cover the impacts of policy changes at regional and household levels (Huang and Li, 2003; Huang et al., 2003).

A.5.5.2 Model structure and data

CAPSiM is a partial equilibrium model for 19 crop, livestock and fishery commodities, including all cereals (four types), sweet potato, potato, soybean, other edible oil crops, cotton, vegetable, fruits, other crops, six livestock products, and one aggregate fishery sector, which together account for more than 90% of China's agricultural output. CAPSiM is simultaneously run at the national, provincial (31) and household (by different income groups) levels. It is the first comprehensive model for examining the effects of policies on China's national and regional food economies, as well as household income and poverty.

CAPSiM includes two major modules for supply and demand balances for each of 19 agricultural commodities. Supply includes production, import, and stock changes. Demand includes food demand (specified separately for rural and urban consumers), feed demand, industrial demand, waste, and export demand. Market clearing is reached simultaneously for each agricultural commodity and all 19 commodities (or groups).

Production equations, which are decomposed by area and yield for crops and by total output for meat and other products, allow producers' own- and cross-price market responses, as well as the effects of shifts in technology stock on agriculture, irrigation stock, three environmental factors—erosion, salinization, and the breakdown of the local environment—and yield changes due to exogenous shocks of climate and other factors (Huang and Rozelle, 1998b; deBrauw et al., 2004). Demand equations, which are broken out by urban and rural consumers, allow consumers' own- and cross-price market responses, as well as the effects of shifts in income, population level, market development and other shocks (Huang and Rozelle, 1998a; Huang and Bouis, 2001; Huang and Liu, 2002).

Most of the elasticities used in CAPSiM were estimated econometrically at CCAP using state-of-the-art econometrics, including assumptions for consistency of estimated parameters with theory. Demand and supply elasticities vary over time and across income groups. Recently, CAPSiM shifted its demand system from double-log to an "Almost Ideal Demand System" (Deaton and Muellbauer, 1980).

CAPSiM generates annual projections for crop production (area, yield and production), livestock and fish production, demand (food, feed, industrial, seed, waste, etc), stock changes, prices and trade. The base year is 2001 (average of 2000-2002) and is currently being updated to 2004 The model is written in Visual C++.

A.5.5.3 Application

CAPSiM has been frequently used by CCAP and its collaborators in various policy analyses and impact assessments. Some examples include China's WTO accession and implications (Huang and Rozelle, 2003; Huang and Chen, 1999), trade liberalization, food security, and poverty (Huang et al., 2003; Huang et. al., 2005a and 2005b), R&D investment policy and impact assessments (Huang et al., 2000), land use policy change and its impact on food prices (Xu et. al., 2006), China's food demand and supply projections (Huang et. al., 1999; Rozelle et al., 1996; Rozelle and Huang, 2000), and water policy (Liao and Huang, 2004).

A.5.5.4 Uncertainty

Tables A.5.8 and A.5.9 below summarize points related to uncertainty in the model, based on the level of agreement and amount of evidence.

Table A.5.8 Overview of major uncertainties in CAPSiM

Model component	Uncertainty
Model structure	• Based on partial equilibrium theory (equilibrium between demand and supply of all commodities and production factors) • One country model (international prices are exogenous)
Parameters	Input parameters: • Some household data on production and consumption may not be consistent with national and provincial demand and supply functions • Elasticities underlying the national and provincial demand and supply functions • International commodity prices • Drivers Output parameters: • Annual levels of food and agricultural production, stock changes, food and other demands, imports and exports, and domestic prices at national level • Annual levels of food and agricultural production, food and other demands at provincial and household level
Driving force	Economic and demographic drivers: • Per capita rural and urban income • Population growth and urbanization Technological drivers • Yield response with respect to research investment, irrigation, and others • Livestock feed rations Policy drivers • Cultivated land expansion/control • Public investment (research, irrigation, environmental conservation, etc.) • Trade policy • Others
Initial condition	Baseline: Three-year average centered on 2001 of all input parameters and assumptions for driving forces
Model operation	Visual C++ programming language

Table A.5.9 Level of confidence in different types of scenario calculations with CAPSiM

		Established but incomplete	**Well established**
Level of Agreement/ Assessment	**High**	• Projections of R&D and irrigation investment • Projections of livestock feed ratios • Impacts on farmers income	• Changes in crop area and yield • Changes in food consumption in both rural and urban areas • Food production and consumption at household level by income group
	Low	**Speculative**	**Competing explanations** • Projections of commodity prices • Commodity trade
		Low	**High**
		Amount of evidence (theory, observations, model outputs) More than 20 papers published in Chinese and international journals based on CAPSiM	

A 5.6   Gender (GEN)-Computable General Equilibrium (CGE)

A.5.6.1 Introduction

The Gen-CGE model developed for India is based on a Social Accounting Matrix (SAM) using the Indian fiscal year 1999-2000 as the base year (Sinha and Sangeeta, 2000). Generally SAMs are used as base data set for CGE Models where one can take into account multi-sectoral, multi-class disaggregation. In determining the results of policy simulations generated by CGE model, a base-year equilibrium data set is required, which is termed calibration. Calibration is the requirement that the entire model specification be capable of generating a base year equilibrium observation as a model solution. There is a need for construction of a data set that meets the equilibrium conditions for the general equilibrium model, viz. demand equal supplies for all commodities, non-profits are made in all industries, all domestic agents have demands that satisfy their budget constraints and external sector is balanced. A SAM provides the most suitable disaggregated equilibrium data set for the CGE model.

The SAM under use distinguishes different sectors of production having a thrust on the agricultural sectors and different factors of production distinguished by gender. The workers are further distinguished into rural, urban, agricultural, non agricultural and casual and regular types. The other important feature of the SAM is the distinction of various types of households and each household type being identified with information on gender worker ratios. As the model incorporates the gendered factors of production it is enabled to carry out counterfactual analysis to see the impact of trade policy changes on different types of workers distinguished by gender which in turn allows the study of welfare of households again distinguished by ratio of workers by gender. Households are divided in to rural and urban groups, distinguished by monthly per capita expenditure (MPCE) levels. Rural households include poor agriculturalists, with MPCE less that Rs. 350; non-poor agriculturalists (above Rs. 351); and non-agriculturalists at all levels of income. Urban households are categorized as poor, with MPCE of less than Rs. 450 and the non-poor, with MPCE of between Rs. 451 and 750.

A.5.6.2 Model structure and data

The Gen-CGE model follows roughly the standard neoclassical specification of general equilibrium models. Markets for goods, factors, and foreign exchange are assumed to respond to changing demand and supply conditions, which in turn are affected by government policies, the external environment, and other exogenous influences. The model is Walrasian in that it determines only relative prices and other endogenous variables in the real sphere of the economy. Sectoral product prices, factor prices, and the foreign exchange rate are defined relative to a price index, which serves as the numeraire. The production technology is represented by a set of nested Cobb-Douglas and Leontief functions. Domestic output in each sector is a Leontief function of value-added and aggregate intermediate input use. Value-added is a Cobb-Douglas function of the primary factors, like capital and labor. Fixed input coefficients are specified in the intermediate input cost function. The model assumes imperfect substitutability, in each sector, between the domestic product and imports. All firms are assumed to be price takers for all imports. What is demanded is the composite consumption good, which is a constant elasticity of substitution (CES) aggregation of imports and domestically produced goods. Similarly, each sector is assumed to produce differentiated goods for the domestic and export markets. The composite production good is a constant elasticity of transformation (CET) aggregation of sectoral exports and domestically consumed products. Such product differentiation permits two-way trade and gives some realistic autonomy to the domestic price system. Based on the small-country assumption, domestic prices of imports and exports are expressed in terms of the exchange rate and their foreign prices, as well as the trade tax. The import tax rate represents the sum of the import tariff, surcharge, and applicable sales tax for each commodity group. The foreign exchange rate, an exogenous variable in the base model, is in real terms. The deflator is a price index of goods for domestic use; hence, this exchange rate measure represents the relative price of tradable goods vis-a-vis nontradables (in units of domestic currency per unit of foreign currency).

A.5.6.3 Application

The GEN-CGE model can be used for studying the impact of tariff changes, removal of non-tariff barriers (measured as tariff equivalents), changes in world GDP, changes in world prices, and changes in agricultural technology on employment by sector, prices, household income and welfare. One version of this model has been used for studying the impact of trade reforms in India in 2003 under a project with IDRC in Canada.

A.5.6.4 Uncertainty

Table A.5.10 Overview of major uncertainties in GEN-CGE model

Model Component	Uncertainty
Model Structure	Labor skill
Parameters	Taken from past studies, literature
Driving force	Exogenous variables to the model
Initial condition	Base level SAM
Model operation	Data based

Table A.5.11 Level of confidence for scenario calculations

Level of Agreement/ Assessment	High	Established but incomplete • Trade reform analysis on employment	Well-established • Trade reform analysis on the economy
	Low	Speculative • The impact on migration of workers	Competing Explanations • Trade off between welfare and growth
		Low	High
	Amount of Evidence (Theory, Observations, Model Outputs): Please see references for model outputs		

A 5.7   The Livestock Spatial Location-Allocation Model (SLAM)

A.5.7.1 Introduction

Seré and Steinfeld (1996) developed a global livestock production system classification scheme. In it, livestock systems fall into four categories: landless systems, livestock only/rangeland-based systems (areas with minimal cropping), mixed rainfed systems (mostly rainfed cropping combined with livestock) and mixed irrigated systems (a significant proportion of cropping uses irrigation and is interspersed with livestock). A method has been devised for mapping the classification, based on agroclimatology, land cover, and human population density (Kruska et al., 2003). The classification system can be run in response to different scenarios of climate and population change, to give very broad-brush indications of possible changes in livestock system distribution in the future.

A.5.7.2 Model structure and data

The livestock production system proposed by Seré and Steinfeld (1996) is made up of the following types:

• Landless monogastric systems, in which the value of production of the pig/poultry enterprises is higher than that of the ruminant enterprises.

• Landless ruminant systems, in which the value of production of the ruminant enterprises is higher than that of the pig/poultry enterprises.

- Grassland-based systems, in which more than 10% of the dry matter fed to animals is farm produced and in which annual average stocking rates are less than ten temperate livestock units per hectare of agricultural land.
- Rainfed mixed farming systems, in which more than 90% of the value of non-livestock farm production comes from rainfed land use, including the following classes.
- Irrigated mixed farming systems, in which more than 10% of the value of non-livestock farm production comes from irrigated land use.

The grassland-based and mixed systems are further categorized on the basis of climate: arid – semiarid (with a length of growing period < 180 days), humid-subhumid (Length of Growing Period or LGP > 180 days), and tropical highlands/temperate regions. This gives 11 categories in all. This system has been mapped using the methods of Kruska et al. (2003), and is now regularly updated with new datasets (Kruska, 2006). For land-use/cover, we use version 3 of the Global Land Cover (GLC) 2000 data layer (Joint Research Laboratory, 2005). For Africa, this included irrigated areas, so this is used instead of the irrigated areas database of Döll and Siebert (2000), which is used for Asia and Latin America. For human population, we use new 1-km data (GRUMP, 2005). For length of growing period, we use a layer developed from the WorldCLIM 1-km data for 2000 (Hijmans et al., 2004), together with a new "highlands" layer for the same year based on the same dataset (Jones and Thornton, 2005). Cropland and rangeland are now defined from GLC 2000, and rock and sand areas are now included as part of rangelands.

The original LGP breakdown into arid-semiarid, humid-subhumid and highland-temperate areas has now been expanded to include hyper-arid regions, defined by FAO as areas with zero growing days. This was done because livestock are often found in some of these regions in wetter years when the LGP is greater than zero. Areas in GLC 2000 defined as rangeland but having a human population density greater than or equal to 20 persons per km^2 as well as a LGP greater than 60 (which can allow cropping) are now included in the mixed system categories.

The landless systems still present a problem, and are not included in version 3 of the classification. Urban areas have been left as defined by GLC 2000. To look at possible changes in the future, we use the GRUMP population data and project human population out to 2030 and 2050 by pro-rata allocation of appropriate population figures (e.g., the UN medium-variant population data for each year by country, or the Millennium Ecosystem Assessment country-level population projections). LGP changes to 2030 and 2050 are projected using downscaled outputs of coarse-gridded GCM outputs, using methods outlined in Jones and Thornton (2003).

A.5.7.3 Application

The mapped Seré and Steinfeld (1996) classification was originally developed for a global livestock and poverty mapping study designed to assist in targeting research and development activities concerning livestock (Thornton et al., 2002; 2003). Estimates of the numbers of poor livestock keepers by production system and region were derived and mapped. This information was used in the study of Perry et al. (2002), which was carried out to identify priority research opportunities that can improve the livelihoods of the poor through better control of animal diseases in Africa and Asia. Possible changes in livestock systems and their implications have been assessed for West Africa (Kristjanson et al., 2004). The methods have recently been used in work to assess the spatial distribution of methane emissions from African domestic ruminants to 2030 (Herrero et al., 2006), and in a study to map climate vulnerability and poverty in sub-Saharan Africa in relation to projected climate change (Thornton et al., 2006).

A.5.7.4 Uncertainty

Uncertainties in the scheme are outlined in Table A.5.12, together with levels of confidence for scenario calculations in Table A.5.13.

Table A.5.12 Major uncertainties in the mapped Seré & Steinfeld (1996) classification

Model component	Uncertainty
Model Structure	• Based on thresholds associated with human population density and length of growing period • Also based on land-cover information that is known to be currently weak with respect to cropland identification • The global classification is quite coarse, and no differentiation is made of the mixed systems
Parameters	Inputs: • Land cover, length of growing period, human population density, irrigated areas, urban areas • Observed or modeled livestock densities Outputs: • Areas associated with grassland-based systems and mixed crop-livestock systems (rainfed and irrigated), broken down by AEZ (which can then be combined with other national or sub-national information, such as poverty rates)
Driving force	Even at the broad-brush level, population change and climate change will not be the only drivers of land-use change in livestock-based systems, globally
Initial condition	Some validation of the systems layers has been carried out for current conditions, but more is needed
Model operation	Assembling the input data and running the classification is not an automated procedure. It requires separate sets of FORTRAN programmes for estimating changing agroclimatological conditions; and various sets of ArcInfo scripts for spatially allocating population data and rerunning the classification

Table A.5.13 Level of confidence for scenario calculations

Level of Agreement/ Assessment	High	Established but incomplete • Agricultural and land-use intensification processes	Well-established • Impacts of human population densities on agricultural land-use
	Low	Speculative • Climate change scenarios • Human population change scenarios • Impacts of changing climate on agricultural land-use	Competing Explanations • Different or expanded sets of variables as drivers of system intensification
		Low	High
		Amount of Evidence (Theory, Observations, Model Outputs)	

A 5.8 Global Methodology for Mapping Human Impacts on the Biosphere (**GLOBIO 3)**

A.5.8.1 Introduction

Biodiversity as defined by the Convention on Biological Diversity (CBD) encompasses the diversity of genes, species, and ecosystems. The 2010 target agreed by the CBD Conference of the Parties (COP) in 2002 specifies a significant reduction in the rate of loss of biodiversity.

Biodiversity loss is defined as the long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured at global, regional and national levels. A number of provisional indicators of biodiversity loss have been listed for use at a global scale and suggested for use at a regional or national scale as appropriate (UNEP, 2006). These indicators include trends in the extent of biomes/ecosystems/habitats, trends in the abundance or range of selected species, coverage of protected areas, threats to biodiversity and trends in fragmentation or connectivity of habitats.

The GLOBIO3 model produces a response indicator on an aggregated level, called the Mean Species Abundance (MSA) relative to the original abundance of species in each natural biome. The model allows us to incorporate this indicator in scenario projections, being uniquely able to project trends in the abundance of species (SCBD/MNP, 2007). A large number of species-climate or species-habitat response models exist, which examine the response of individual species to change. GLOBIO3 differs from these models as it measures habitat integrity through the lens of remaining species-level diversity, rather than individual species abundance.

A.5.8.2 Model structure and data

The GLOBIO 3 model framework describes biodiversity by means of estimating remaining mean species abundance of original species, relative to their abundance in primary vegetation. This measure of MSA is similar to the Biodiversity Integrity Index (Majer and Beeston, 1996) and the Biodiversity Intactness Index (Scholes and Biggs, 2005) and can be considered as a proxy for CBD indicators (UNEP, 2004).

The core of GLOBIO 3 is a set of regression equations describing the impact on biodiversity of the degree of pressure using dose–response relationships. These dose–response relationships are derived from a database of observations of species response to change. The database includes separate measures of MSA, each in relation to different degrees of pressure exerted by various pressure factors or driving forces. The entries in the database are all derived from studies in peer-reviewed literature, reporting either on change through time in a single plot, or on response in parallel plots undergoing different pressures.

The current version of the database includes data from about 500 reports: about 140 reports on the relationship between species abundance and land cover or land use, 50 on atmospheric N deposition (Bobbink, 2004), over 300 on impacts of infrastructure (UNEP, 2001) and several literature reports on minimal area requirements of species.

The driving forces (pressures) incorporated within the model and their sources are as follows:

- Land cover change (IMAGE)
- Land use intensity (IMAGE / GLOBIO3)
- Nitrogen deposition (IMAGE)
- Infrastructure development (IMAGE / GLOBIO2)
- Climate change (IMAGE)

Climate change is treated differently from other drivers in GLOBIO3, as the empirical evidence compiled in GLOBIO dose-response relationships so far is limited to areas that are already experiencing significant impacts of change (such as the Arctic and montane forests). The current implementation in the model is based on changing temperature only. Estimates from a European model of the proportion of species lost per biome (Bakkenes et al., 2002; Leemans and Eickhout, 2004; Bakkenes et al., 2006) for increasing levels of temperature are applied within the GLOBIO3 model on a global scale. This regional bias and the absence of a modeled response to changes in moisture availability are important areas for model improvement.

Some responses to change take some time to become apparent. The loss of species from a particular area may take 30 years or may be instantaneous, depending on the type and strength of the pressure. Because of these lags, the model outcome portrays the possible impact over the short to medium term (~5 to 30 years). These lags must be better characterized, and for that the underlying databases are developed further.

There is little quantitative information about the interaction between pressures. Various assumptions can therefore be included in the model, ranging from 'all interact' (only the maximum response is delivered) to 'no interaction' (responses to each pressure are cumulative). The GLOBIO 3 model calculates the overall MSA value by multiplying the MSA values for each driver for each IMAGE 0.5 by 0.5 degree grid cell according to:

$$MSA_i = MSA_{LU_i} MSA_{N_i} MSA_{I_i} MSA_{F_i} MSA_{CC_i}$$ (Equation 1)

where i is the index for the grid-cell, MSAXi relative mean species abundance corresponding to the drivers LU (land cover/use), N (atmospheric N deposition), I (infrastructural development), F (fragmentation) and CC (climate change). MSALUi is the area-weighted mean over all land-use categories within a grid cell.

The model relates 0.5° IMAGE maps to Global Land Cover 2000 as a base map at a 1-km scale, based on a series of simple decision rules. These maps are used to estimate the response to changes in land cover and land use intensity within each 0.5° grid cell. The land-use cover maps and the maps representing other pressures are used to generate maps of the share of remaining biodiversity, which may be derived either in terms of remaining share of original species richness, or remaining share of mean original species abundance. More data is being collated for abundance than for richness – this is the favored indicator, as it is closest to those specified by CBD. Outputs are derived at a 0.5° scale and can be scaled up to IAASTD regions.

A.5.8.3 Application

GLOBIO3 has been used in global and regional assessments. GLOBIO3 analyses contributed to an integrated assessment for the Himalaya region (Nellemann, 2004); for deserts of the world and the Global Biodiversity Outlook (CBD/MNP, 2007)

A.5.8.4 Uncertainty

GLOBIO3 reflects a relatively new model approach. The level of confidence is highly related to the data quality and quantity, a lot of which is derived from other models, in particular, the IMAGE 2.4 model, infrastructure maps (Digital Chart of the World or DCW) and other land cover maps. The biodiversity indicator generated (MSA) is designed to be compatible with the trends in abundance of species indicator as specified by CBD. Other indicators might lead to different results. However the patterns of the global analyses are in line with earlier global analyses. Table A.5.14 provides an overview of major parameters, and model structure.

Table A.5.14 Overview of major uncertainties in the GLOBIO 3 model

Model component	Uncertainties
Model structure	• Coupling of data from different sources and resolutions, e.g. from IMAGE, Global Land Cover database 2000. • Applying and combining statistical (regression) equations on input data to derive
Parameters	Input: • Regression parameter for relationships between drivers and biodiversity output indicator (MSA) Output: • Biodiversity indicator is Mean species abundance of original species relative to their original abundance (MSA)
Driving force	• Climate (mean annual temperature) • Land use (incl. forestry) and land use pattern • Infrastructure • Nitrogen deposition
Initial condition	• Baseline for biodiversity is 'original vegetation' as simulated by the BIOME model in the IMAGE 2.4 model (Prentice et al., 1992) • Baseline for input are calculated maps for 2000 from the IMAGE model
Model operation	ArcGIS maps, Access data bases, VB scripting language

Table A.5.15 Level of confidence in different types of scenario calculations from GLOBIO3

Level of Agreement/ Assessment	High	**Established but incomplete** • Dose-response relationships based on existing studies with a regional bias.	**Well established** • Selection of pressure factors
	Low	**Speculative** • Interaction between pressure factors	**Competing explanations** • Use of species distribution and abundance
		Low	**High**
		Amount of evidence **(theory, observations, model outputs)**	

A 5.9   EcoOcean

A.5.9.1 Introduction

EcoOcean is an ecosystem model complex that can evaluate fish supply from the world's oceans. The model is constructed based on the Ecopath with Ecosim modeling approach and software, and includes a total of 42 functional groupings. The spatial resolution in this initial version of the Ecoocean model is based on FAO marine statistical areas, and it is run with monthly time-steps for the time period from 1950. The model is parameterized using an array of global databases, most of which are developed by or made available through the Sea Around Us project. Information about spatial fishing effort by fleet categories will be used to drive the models over time. The models for the FAO areas will be tuned to time series data of catches for the period 1950 to the present, while forward looking scenarios involving optimization routines will be used to evaluate the impact of GEO4 scenarios on harvesting of marine living resources.

A.5.9.2 Model structure and data

The Ecopath with Ecosim (EwE) modeling approach has three main components:

• Ecopath – a static, mass-balanced snapshot of the system;

• Ecosim – a time dynamic simulation module for policy exploration; and

- Ecospace – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas.

The initial EcoOcean model will be composed of 19 EwE models. The EwE approach, its methods, capabilities and pitfalls are described in detail by Christensen and Walters (2004). The foundation of the EwE suite is an Ecopath model (Christensen and Pauly, 1992; Pauly et al., 2000), which creates a static mass-balanced snapshot of the resources in an ecosystem and their interactions, represented by trophically linked biomass "pools." The biomass pools consist of a single species, or species groups representing ecological guilds. Ecopath data requirements are relatively simple, and generally already available from stock assessment, ecological studies, or the literature: biomass estimates, total mortality estimates, consumption estimates, diet compositions, and fishery catches. The parameterization of an Ecopath model is based on satisfying two 'master' equations. The first equation describes the how the production term for each group can be divided:

Production =   catch + predation + net migration + biomass accumulation + other
                     mortality

The second 'master' equation is based on the principle of conservation of matter within a group:

Consumption = production + respiration + unassimilated food

Ecopath sets up a series of linear equations to solve for unknown values establishing mass-balance in the same operation.

Ecosim provides a dynamic simulation capability at the ecosystem level, with key initial parameters inherited from the base Ecopath model. The key computational aspects are in summary form:

- Use of mass-balance results (from Ecopath) for parameter estimation;

- Variable speed splitting enables efficient modeling of the dynamics of both "fast" (phytoplankton) and "slow" groups (whales);

- Effects of micro-scale behaviors on macro-scale rates: top-down vs. bottom-up control incorporated explicitly.

- Includes biomass and size structure dynamics for key ecosystem groups, using a mix of differential and difference equations. As part of this EwE incorporates:
    - age structure by monthly cohorts, density- and risk-dependent growth;

    - Numbers, biomass, mean size accounting via delay-difference equations;

      ○   Stock-recruitment relationship as 'emergent' property of competition/predation interactions of juveniles.

Ecosim uses a system of differential equations that express biomass flux rates among pools as a function of time varying biomass and harvest rates, (Walters et al., 1997, 2000). Predator prey interactions are moderated by prey behavior to limit exposure to predation, such that biomass flux patterns can show either bottom-up or top down (trophic cascade) control Walters et al., 2000). Conducting repeated simulations Ecosim simulations allows for the fitting of predicted biomasses to time series data, thereby providing more insights into the relative importance of ecological, fisheries and environmental factors in the observed trajectory of one or more species or functional groups.

A.5.9.3 Application

The core of this global ocean model is Ecopath with Ecosim, which has been used for a number of regional and sub-regional models throughout the world. This global ocean model will be used for this assessment and the GEO4 Assessment.

A.5.9.4 Uncertainty

Table A.5.16 Overview of major uncertainties in EcoOcean Model

Model component	Uncertainty
Model structure	low
Parameters	Input parameters • Most have medium to low uncertainty; a few have high uncertainty
Driving force effort: either direct or relative	Medium to high depending on the FAO area at this stage
Initial condition	low
Model operation	medium

Table A.5.17 Level of confidence for scenario calculations with EcoOcean model

Level of Agreement/ Assessment	High	• Established but incomplete: • Catches • Value • Landing diversity	Well-established: • Marine trophic index (MTI)
	Low	Speculative Jobs	Competing Explanations
		Low	High
	Amount of Evidence (Theory, Observations, Model Outputs)		