

**International Model for Policy Analysis of Agricultural Commodities and  
Trade (IMPACT): Model Description**

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## INTRODUCTION

IMPACT – the International Model for Policy Analysis of Agricultural Commodities and Trade – was developed at IFPRI at the beginning of the 1990s, upon the realization that there was a lack of long-term vision and consensus among policy makers and researchers about the actions that are necessary to feed the world in the future, reduce poverty, and protect the natural resource base. In 1993, these same long-term global concerns launched the 2020 Vision for Food, Agriculture and the Environment Initiative. This initiative created the opportunity for further development of the IMPACT model, and in 1995 the first results using IMPACT were published as a 2020 Vision discussion paper: *Global Food Projections to 2020: Implications for Investment* (Rosegrant, Agcaoili-Sombilla and Perez, 1995), in which the effects of population, investment, and trade scenarios on food security and nutrition status, especially in developing countries, were analyzed.

IMPACT has been used in several important research publications, which examine the linkage between the production of key food commodities and food demand and security at the national level. Such examples can be found in the paper looking at the relationship between meat-intensive diets in developed nations and food security in developing countries, *Alternative Futures for World Cereal and Meat Consumption* (Rosegrant, Leach and Gerpacio, 1999); or the article *Global Projections for Root and Tuber Crops to the Year 2020* (Scott, Rosegrant and Ringler, 2000), which gives a detailed analysis of roots and tuber crops and their importance to the food economies of the poor. The report *Livestock to 2020: The next food revolution* (Delgado *et al.*, 1999) assesses the rise in livestock demand in developing countries that was triggered by rising incomes in recent decades, and considers the current and expected future developments of this “livestock revolution”, as well as its implications for policy.

The IMPACT model has also been employed in regional studies, such as the *Asian Economic Crisis and the Long-Term Global Food Situation* (Rosegrant and Ringler, 2000) and *Transforming the Rural Asian Economy: the Unfinished Revolution* (Rosegrant and Hazell, 2000), which were both written in response to the Asian financial crisis of 1997 and which try to assess its impact on the regional food economy. The most comprehensive set of results for IMPACT are published in the book *Global Food Projections to 2020* (Rosegrant *et al.*, 2001). These projections – which were presented in 2001 at the IFPRI-sponsored conference in Bonn entitled: *Sustainable Food Security for All by 2020* – are presented with details on the demand system and other underlying data used in

the projections work, and cover both global and regionally-focused projections. This publication is also the first in a series of research outputs that IFPRI hopes to use to provide policy advice on the necessary investments that need to be made by national and regional policy makers in order to sustain the levels of food production and nutrition that are required by projected global demographic and economic changes. IMPACT also provided the first comprehensive policy evaluation of global fishery production and projections for demand of fish products in the book *Fish to 2020: Supply and Demand in Changing Global Markets* (Delgado, Wada, Rosegrant, Meijer and Ahmed, 2003). A complete list of the research published using the IMPACT modeling framework is provided in Appendix 1, including reports for international organizations, such as the World Bank, the Asian Development Bank, the FAO, and national governments.

While the primary IMPACT model has gained recognition within the policy research community as a leading agricultural sector model for the assessment of the global food production and the performance of global food markets, it assumes “normal” base climate conditions, which is maintained throughout its 30-year projections horizon. As such, the impacts of annual climate variability on food production demand and trade are not embodied within the model or reflected in its results. The recognition that the long-term change in water demand and availability—and particularly the rapidly increasing demand in non-agricultural water uses—as well as the year-to-year variability in rainfall and runoff would affect future food production, demand, and trade led to a renewed effort on the part of IFPRI and partner collaborators to make more explicit linkages between food production and water availability in an integrated modeling framework. The result of this research has led to the development of the IMPACT-WATER model, which integrates the primary IMPACT model with a water simulation module (WSM) that balances water availability and uses within various economic sectors, at the global and regional scale.

IMPACT-WATER – through the combination of the IMPACT and WSM models – incorporates water availability as a driving variable with observable flows and storage to examine the impact of water availability on food supply, demand and prices. This framework allows exploration of the relationship between water availability and food demand at trade at a variety of spatial scales – ranging from river basins, countries and more aggregated regions, to the global level. Water supply and demand and crop production are first assessed at the river-basin scale, and crop production is then summed to the national level, where food demand and trade are modeled. While

the primary IMPACT model divided the world into 36 countries and regions, the IMPACT-WATER model uses a finer disaggregation of 281 “food-producing units” – which represent the spatial intersection of 115 economic regions and 126 river basins – out of recognition of the fact that significant climate and hydrologic variations within regions make the use of large spatial units inappropriate for water resource assessment and modeling. Of the countries represented within the IMPACT-WATER model, China, India and the United States (which together produce about 60 percent of the world’s cereals) have the highest level of sub-national disaggregation and are divided into 9, 13 and 14 major river basins, respectively, while the other countries or regions considered in IMPACT are combined into the remaining 90 basins.

Ongoing research has also expanded the set of agricultural crop commodities to 40, which include fish from both capture and aquaculture, groundnuts, cotton, fodder crops and major dryland grains and pulses, such as sorghum, millet, chickpeas and pigeonpeas. Given the prominence of many of dryland crops in the semi-arid tropics and their important linkage to livestock through feed, along with other fodder crops, we felt these additions were necessary to fully understanding the drivers behind projected future growth in global oil, meat and milk demand. The importance of many of these commodities, including aquaculture, in global water demand also warranted their full inclusion into the model.

Policy analyses based on alternative scenarios analyzed with IMPACT-WATER were published in an IFPRI book titled *World Water and Food to 2025: Dealing with Scarcity* (Rosegrant, Cai and Cline, 2002). Another paper that has used results from IMPACT-WATER to make policy evaluations is a study prepared for the North American Commission for Environmental Cooperation titled *Modeling Water Availability and Food Security: A North American Application of the IMPACT-WATER Model* (Rosegrant, Runge and Cai), which looked at implications of NAFTA on water use and agricultural production in North America. IMPACT-WATER is also currently used for a World Bank report on the role of agriculture to achieve the Millennium Development Goals and a small effort by the US EPA on the role of greenhouse gas mitigation for rice in China.

For the sake of ease in documentation and citations and because IMPACT-WATER forms the basis for all work with this model, we will simply refer to the current model as IMPACT—not to be confused with the older model which lacks integration with WSM.

The next section discusses the food and water components of the IMPACT model, including

a technical description that shows the equations and the sources of the data used in the model. A general overview of the countries/ regions and commodities is given in Appendix 2, while the definitions of the river basins are shown in Appendix 3. After a description of the commodities, in Appendix 4, a schematic overview of the integrated modeling framework is given in Appendix 5.

# THE MODEL

## I. Basic Methodology on Food

Encompassing countries and regions in the world and the main agricultural commodities produced in the world (see Boxes 1 and 2 at the end of the document), the system of equations on food offers a methodology for analyzing baseline and alternative scenarios for global food demand, supply, trade, income and population. Within each country or regional sub-model, supply, demand, and prices for agricultural commodities are determined. These country and regional agricultural sub-models are linked through trade.

Supply and demand functions incorporate supply and demand elasticities to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets.

### I.A. Food Supply

#### I.A.a. Crop Production

Domestic crop production is determined by area and yield response functions. Harvested area is specified as a response to the crop's own price, the prices of other competing crops, the projected rate of exogenous (non-price) growth trends in harvested area, and water (Equation 1). The projected exogenous trend in harvested area captures changes in area resulting from factors other than direct crop price effects, such as expansion through population pressure and contraction from soil degradation or conversion of land to nonagricultural uses. Yield is a function of the commodity price, the prices of labor and capital, water, and a projected nonprice exogenous trend factor. The trend factor reflects productivity growth driven by technology improvements, 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., and water (Equation 2). Annual production of commodity  $i$  in country  $n$  is then estimated as the product of its area and yield (Equation 3).

Area response:

$$AC_{mi} = \alpha_{mi} \times (PS_{mi})^{\varepsilon_{im}} \times \prod_{j \neq i} (PS_{mj})^{\varepsilon_{ijn}} \times (1 + gA_{mi}) - \Delta AC_{mi}(WAT_{mi}); \quad (1)$$

Yield response:

$$YC_{mi} = \beta_{mi} \times (PS_{mi})^{\gamma_{im}} \times \prod_k (PF_{mk})^{\gamma_{ikn}} \times (1 + gCY_{mi}) - \Delta YC_{mi}(WAT_{mi}); \quad (2)$$

Production:

$$QS_{mi} = AC_{mi} \times YC_{mi}; \quad (3)$$

where	$AC$	=	crop area
	$YC$	=	crop yield
	$QS$	=	quantity produced
	$PS$	=	effective producer price
	$PF$	=	price of factor or input $k$ (for example labor and capital)
	$\prod$	=	product operator
	$i, j$	=	commodity indices specific for crops
	$k$	=	inputs such as labor and capital
	$n$	=	country index
	$t$	=	time index
	$gA$	=	growth rate of crop area
	$gCY$	=	growth rate of crop yield
	$\varepsilon$	=	area price elasticity
	$\gamma$	=	yield price elasticity
	$\alpha$	=	crop area intercept
	$\beta$	=	crop yield intercept
	$\Delta AC$	=	crop area reduction due to water stress
	$\Delta YC$	=	crop yield reduction due to water stress
	$WAT$	=	water variable

### I.A.a.1 Incorporation of Water in Crop Area Functions

Reduction of crop harvest area  $\Delta AC$  is calculated as:

$$\Delta AC^i = 0, \text{ if } \frac{ETA^i}{ETM^i} > E^*, \text{ otherwise} \quad (4)$$

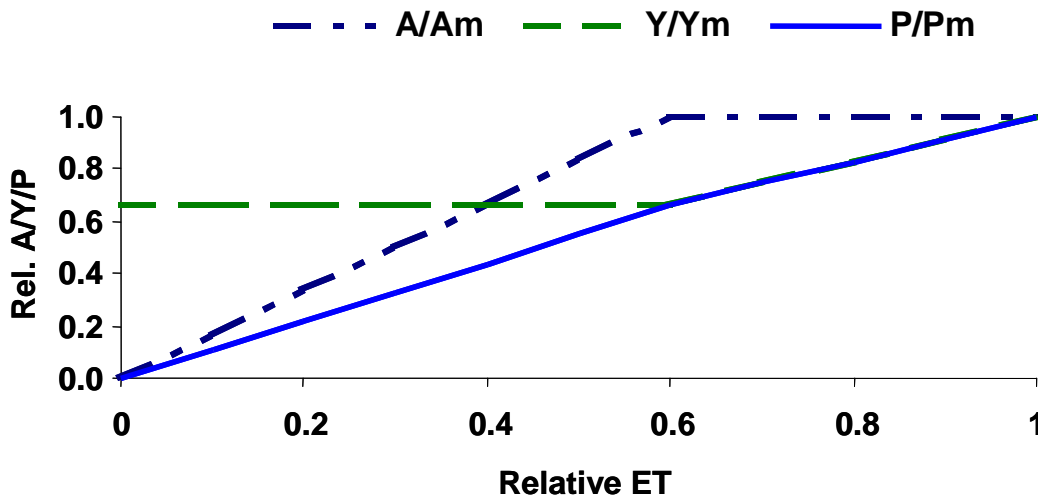
$$\Delta AC^i = AC^i \cdot \left[ 1 - \left( \frac{ETA^i}{ETM^i} / E^{*i} \right) \right] \text{ for irrigated area} \quad (5)$$

$$\Delta AC^i = AC^i \cdot \left[ 1 - \left( ky^i \cdot \left( 1 - \frac{ETA^i}{ETM^i} / E^{*i} \right) \right)^{\gamma} \right] \text{ for rainfed areas} \quad (6)$$

where

- $ETA$  = actual crop evapotranspiration in the crop growth season
- $ETM$  = potential crop evapotranspiration in the crop growth season (see description later in Equation 24)
- $E^*$  = threshold of relative evapotranspiration, below which farmers reduce crop area
- $ky$  = crop response coefficient to water stress.

Actual crop evapotranspiration includes irrigation water which can be used for crop evapotranspiration ( $NIW$ ) and effective rainfall ( $PE$ ),  $ETA^i = NIW^i + PE^i$  where for rainfed crops,  $NIW = 0$ . The determination of  $NIW$  for irrigated crops and  $PE$  for both rainfed and irrigated crops will be described later. The determination of  $E^*$  is empirical. For irrigated area, farmers can reduce area and increase water application per unit of the remaining area. Assuming  $E^* = ky - 0.25$ , Figure 1 shows relative irrigated yield, area and production versus relative ET. As can be seen, for irrigated area, when  $ETA/ETm > E^*$ , farmers will maintain the entire crop area, and yield is reduced linearly with  $ETA/ETm$ ; and when  $ETA/ETm < E^*$ , farmers will reduce the crop area linearly with  $ETA/ETm$ , and maintain constant crop yield corresponding to  $E^*$ . Equation 5 is derived based on the assumption that total available water can be applied in the remaining irrigated area.



**Figure 1. Relative irrigated yield, area, and production versus relative crop evapotranspiration**

Source: Rosegrant et al (2002).

Notes:  $E^* = 0.6$ ; A indicates area; Am, maximum area; Y, yield; Ym, maximum yield; P, production; and Pm, maximum production.

For the same crop, the value of  $E^*$  is generally much lower for rainfed areas than for irrigated areas. For rainfed area, theoretically, when  $ETA/ETM < E^*$ , farmers will give up all the area. However, in the real world this may not be true. Historic records show that in regions with arid or semi-arid climate, even in a very dry region, the harvested rainfed area does not decline to zero. However, a general empirical relationship between rainfed harvested area and  $ETA/ETM$  is not available from existing studies. We assume the FAO yield-water relationship can be applied to harvested area and water, which is shown in Equation 6, but with a calibration coefficient ( $\gamma$ ). This coefficient for a crop is estimated based on the evaluation of rainfed harvested area and effective rainfall in recent years.

Equations 5 and 6 capture the effect of extreme water shortages on the crop area decision. The parameter  $E^*$  will vary with respect to the sensitivity of crops to water stress. When  $E^*$  equals 1 all adjustments to water shortages are realized through area reduction while crop yield is maintained. For crops that are highly sensitive to water stress, (that is,  $ky > 1.0$ ),  $E^*$  in fact approaches a value of 1.0 (for example, 0.9 or more). For these crops, water shortages are handled by leaving a portion of the land fallow while maintaining yields on the remaining area, a strategy that maximizes crop production and returns given the constrained water availability. For relatively drought-tolerant crops,  $E^*$  has a lower value. For these crops, maximization of production and returns requires spreading the water over as broad an area as possible to maintain production while reducing crop yields.  $E^*$  can be estimated based on a yearly series of historical data including crop area and yield in different basins/countries, or can be estimated through a field survey. The modeling framework currently only incorporates a relationship between  $E^*$  and the crop response to water stress ( $ky$ ). The assumed relationship is  $E^* = ky - 0.25$  for irrigated crops and approximately  $E^* = ky \cdot 0.6$  for rainfed crops.

#### I.A.a.2 Incorporation of Water in Crop Yield Function

Reduction of crop yield  $\Delta YC$  is calculated as:

$$\Delta YC = YC^i \cdot ky^i \cdot (1 - ETA^i / ETM^i) \cdot \left[ \frac{\min_{t \in \text{growthstages}} \left( (1 - ETA_m^{it} / ETM_m^{it}) \right)}{(1 - ETA^i / ETM^i)} \right]^\beta \quad (7)$$

in which  $\beta$  is the coefficient to characterize the penalty item, which should be estimated based on local water application in crop growth stages and crop yield. Here crop yield reduction is calculated

based on seasonal water availability (that is, seasonal ETA), but is “penalized” if water availability in some crop growth stages (months) is substantially below the seasonal level. All other items have been previously defined.

### I.A.b. Livestock Production.

Livestock production is modeled similarly to crop production except that livestock yield reflects only the effects of expected developments in technology (Equation 9). Total number of livestock slaughtered is a function of the livestock’s own price and the price of competing commodities, the prices of intermediate (feed) inputs, and a trend variable reflecting growth in the livestock slaughtered (Equation 8). Total production is calculated by multiplying the slaughtered number of animals by the yield per head (Equation 10).

Number slaughtered:

$$AL_{ti} = \alpha_{ti} \times (PS_{ti})^{\varepsilon_{in}} \times \prod_{j \neq i} (PS_{tj})^{\varepsilon_{jn}} \times \prod_{b \neq i} (PI_{tbn})^{\gamma_{bn}} \times (1 + gSL_{ti}); \quad (8)$$

Yield:

$$YL_{mi} = (1 + gLY_{mi}) \times YL_{t-1,ni}; \quad (9)$$

Production:

$$QS_{mi} = AL_{mi} \times YL_{mi}; \quad (10)$$

where	$AL$	=	number of slaughtered livestock
	$YL$	=	livestock product yield per head
	$PI$	=	price of intermediate (feed) inputs
	$i, j$	=	commodity indices specific for livestock
	$b$	=	commodity index specific for feed crops
	$gSL$	=	growth rate of number of slaughtered livestock
	$gYL$	=	growth rate of livestock yield
	$\alpha$	=	intercept of number of slaughtered livestock
	$\varepsilon$	=	price elasticity of number of slaughtered livestock
	$\gamma$	=	feed price elasticity

The remaining variables are defined as for crop production.

## I.B. Demand

Domestic demand for a commodity is the sum of its demand for food, feed, and other uses (Equation 16). Food demand is a function of the price of the commodity and the prices of other competing commodities, per capita income, and total population (Equation 11). Per capita income and population increase annually according to country-specific population and income growth rates as shown in Equations 12 and 13. Feed demand is a derived demand determined by the changes in livestock production, feed ratios, and own- and cross-price effects of feed crops (Equation 14). The equation also incorporates a technology parameter that indicates improvements in feeding efficiencies. Demand for feedstock for biofuels production (Equation 15) is derived from the implied demand that various alternatives for the development of ethanol and biodiesel. The demand for other uses is estimated as a proportion of food and feed demand (Equation 16). Note that total demand for livestock consist only of food demand.

Demand for food:

$$QF_{mi} = \alpha_{mi} \times (PD_{mi})^{\varepsilon_{in}} \times \prod_{j \neq i} (PD_{mj})^{\varepsilon_{jn}} \times (INC_m)^{\eta_{in}} \times POP_m; \quad (11)$$

where

$$INC_m = INC_{t-1,ni} \times (1 + gI_m); \quad (12)$$

and

$$POP_m = POP_{t-1,ni} \times (1 + gP_m); \quad (13)$$

Demand for feed:

$$QL_{tnb} = \beta_{tnb} \times \sum_1 (QS_{tnl} \times FR_{tnbl}) \times (PI_{tnb})^{\gamma_{bn}} \times \prod_{o \neq b} (PI_{tnb})^{\gamma_{bon}} \times (1 + FE_{tnb}); \quad (14)$$

Demand for Biofuels:

$$QB_{mi} = f(GM_{mi}, EP_{mi}, PSE_{mi}) \quad (15)$$

Demand for other uses:

$$QE_{mi} = QE_{t-1,ni} \times \frac{(QF_{mi} + QL_{mi})}{(QF_{t-1,ni} + QL_{t-1,ni})}; \quad (16)$$

Total demand:

$$QD_{mi} = QF_{mi} + QL_{mi} + QB_{mi} + QE_{mi}; \quad (17)$$

where	$QD$	=	total demand
	$QF$	=	demand for food
	$QL$	=	derived demand for feed
	$QB$	=	demand for biofuel feedstock
	$QE$	=	demand for other uses
	$PD$	=	the effective consumer price
	$INC$	=	per capita income
	$POP$	=	total population
	$FR$	=	feed ratio
	$FE$	=	feed efficiency improvement
	$PI$	=	the effective intermediate (feed) price
	$GM$	=	government blending mandates
	$EP$	=	energy price
	$PSE$	=	producer subsidy equivalents of both subsidies and trade measures
	$i,j$	=	commodity indices specific for all commodities
	$l$	=	commodity index specific for livestock
	$b,o$	=	commodity indices specific for feed crops
	$gI$	=	income growth rate
	$gP$	=	population growth rate
	$\varepsilon$	=	price elasticity of food demand
	$\gamma$	=	price elasticity of feed demand
	$\eta$	=	income elasticity of food demand
	$\alpha$	=	food demand intercept
	$\beta$	=	feed demand intercept

The rest of the variables are as defined earlier.

### I.C. Prices

Prices are endogenous in the system of equations for food. Domestic prices are a function of world prices, adjusted by the effect of price policies and expressed in terms of the producer subsidy equivalent (PSE), the consumer subsidy equivalent (CSE), and the marketing margin (MI). PSEs and CSEs measure the implicit level of taxation or subsidy borne by producers or consumers relative to world prices and account for the wedge between domestic and world prices. MI reflects other factors such as transport and marketing costs. In the model, PSEs, CSEs, and MIs are expressed as percentages of the world price. To calculate producer prices, the world price is reduced by the MI value and increased by the PSE value (Equation 18). Consumer prices are obtained by adding the MI value to the world price and reducing it by the CSE value (Equation 19). The MI of the intermediate

prices is smaller because wholesale instead of retail prices are used, but intermediate prices (reflecting feed prices) are otherwise calculated the same as consumer prices (Equation 20).

Producer prices:

$$PS_{mi} = [PW_i (1 - MI_{mi})](1 + PSE_{mi}); \quad (18)$$

Consumer prices:

$$PD_{mi} = [PW_i (1 + MI_{mi})](1 - CSE_{mi}); \quad (19)$$

Intermediate (feed) prices:

$$PI_{mi} = [PW_i (1 + 0.5 MI_{mi})](1 - CSE_{mi}); \quad (20)$$

where  $PW$  = the world price of the commodity  
 $MI$  = the marketing margin  
 $PSE$  = the producer subsidy equivalent  
 $CSE$  = the consumer subsidy equivalent

The rest of the variables are as defined earlier.

#### I.D. International Linkage—Trade

The country and regional sub-models are linked through trade. Commodity trade by country is the difference between domestic production and demand (Equation 21). Countries with positive trade are net exporters, while those with negative values are net importers. This specification does not permit a separate identification of both importing and exporting countries of a particular commodity.

Net trade:

$$QT_{mi} = QS_{mi} - QD_{mi} + QSt_{mi}; \quad (21)$$

where  $QT$  = volume of trade  
 $QS$  = domestic supply of the commodity  
 $QD$  = domestic demand of the commodity  
 $QSt$  = held stock of the commodity  
 $i$  = commodity index specific for all commodities

The rest of the variables are as defined earlier.

#### I.E. Algorithm for Solving the Equilibrium Condition

Our systems of equations are written in the General Algebraic Modeling System (GAMS) programming language. The solution of these equations is achieved by using the Gauss-Seidel method algorithm. This procedure minimizes the sum of net trade at the international level and seeks a world market price for a commodity that satisfies Equation 22, the market-clearing condition.

$$\sum_n QT_{mi} = 0; \quad (22)$$

The world price (PW) of a commodity is the equilibrating mechanism such that when an exogenous shock is introduced in the model, PW will adjust and each adjustment is passed back to the effective producer (PS) and consumer (PD) prices via the price transmission equations (Equations 17–19). Changes in domestic prices subsequently affect commodity supply and demand, necessitating their iterative readjustments until world supply and demand balance, and world net trade again equals zero.

#### I.F. Determination of Malnutrition

To determine how the aforementioned scenarios affect food security within Sub-Saharan Africa, we project their nutritional impacts, namely the resultant percentage and number of malnourished children under the age of five. Any child whose weight-for-age is more than two standard deviations below the weight-for-age standard set by the U.S. National Centre for Health Statistics/ World Health Organization is considered malnourished. The IMPACT-WATER model is able to project this number for each scenario, thereby allowing us to compare the relative abilities of various scenarios to foster improvements in food security. The percentage of malnourished children under the age of five is estimated from the average per capita calorie consumption, female access to secondary education, the quality of maternal and child care, and health and sanitation (Rosegrant et al., 2001). The precise relationship used to project the percentage of malnourished children is based on a cross-country regression relationship of Smith and Haddad (2000), and can be written as follows:

$$\Delta_{t,t2000}MAL = - 25.24 \cdot \ln\left(\frac{KCAL_t}{KCAL_{t2000}}\right) - 71.76 \cdot \Delta_{t,t2000}LFEXPRAT - 0.22 \cdot \Delta_{t,t2000}SCH - 0.08 \cdot \Delta_{t,t2000}WATER \quad (23)$$

where *MAL* = percentage of malnourished children  
*KCAL* = per capita kilocalorie availability  
*LFEXPRAT* = ratio of female to male life expectancy at birth  
*SCH* = total female enrollment in secondary education (any age group) as a percentage of the female age-group corresponding to national regulations for secondary education, and  
*WATER* = percentage of population with access to safe water.  
 $\Delta_{t,t2000}$  = the difference between the variable values at time t and the base year t2000.

Most of this data comes from the following sources: the World Health Organization's Global Database on Child Growth Malnutrition, the United Nations Administrative Committee on Coordination- Subcommittee on Nutrition, the World Bank's World Development Indicators, the FAO FAOSTAT database, and the UNESCO UNESCOSTAT database. The per capita calorie consumption variable is derived from two components; these include the amount of calories obtained from commodities included in the model as well as calories from commodities outside the model. Knowing this percentage, the projected number may be calculated using the following equation:

$$NMAL_t = MAL_t \times POP5_t, \quad (24)$$

where *NMAL* = number of malnourished children, and  
*POP5* = number of children 0–5 years old in the population.

Observed relationships between all of these factors were used to create the semi-log functional mathematical model, allowing an accurate estimate of the number of malnourished children to be derived from data describing the average per capita calorie consumption, female access to secondary education, the quality of maternal and child care, and health and sanitation.

## II. Basic Methodology on Water (Water Simulation Module)

The model is based on an optimization approach which minimizes water shortages within the river basin. In the original IMPACT-WATER model, the world was divided into 126 major river basins of various sizes with the goal of achieving accuracy with regard to the basins most important to irrigated agriculture.

### II.A. Water Demand

#### II.A.a Irrigation Water Demand

Irrigation water demand is assessed as crop water requirement based on hydrologic and agronomic characteristics. Net crop water demand (NCWD) in a basin in a year is calculated based on an empirical crop water requirement function (Doorenbos and Pruitt 1979):

$$NCWD = \sum_{cp} \sum_{ct} kc^{cp,ct} \cdot ET_0^{ct} \cdot A^{cp} = \sum_{cp} \sum_{ct} ETM^{ct,cp} \cdot A^{cp} \quad (25)$$

in which  $cp$  is the index of crops,  $ct$  is the index of crop growth stages,  $ET_0$  is the reference evapotranspiration [L],  $kc$  is the crop coefficient, and  $A$  is the crop area.

Part or all of crop water demand can be satisfied by effective rainfall (PE), which is the rainfall infiltrated into the root zone and available for crop use. Effective rainfall for crop growth can be increased through rainfall harvesting technology. Then net irrigation water demand ( $NIRWD$ ), with consideration of effective rainfall use and salt leaching requirement, is:

$$NIRWD = \sum_{cp} \sum_{st} \left( kc^{cp,st} \cdot ET_0^{st} - PE^{cp,st} \right) \cdot AI^{cp} \cdot (1 + LR) \quad (26)$$

in which  $AI$  is the irrigated area.,  $LR$  is the salt leaching factor, which is characterized by soil salinity and irrigation water salinity.

Total irrigation water demand represented in water depletion ( $IRWD$ ) is calculated as:

$$IRWD = NIRWD / BE \quad (27)$$

in which  $BE$  is defined as basin efficiency. The concept of basin efficiency was discussed, and various definitions were provided by Molden, Sakthivadivel, and Habib (2001). The basin efficiency used in this study measures the ratio of beneficial water depletion (crop evapotranspiration and salt

leaching) to the total irrigation water depletion at the river basin scale. Basin efficiency in the base year (1995) is calculated as the ratio of the net irrigation water demand (*NIRWD*, Equation 25) to the total irrigation water depletion estimated from records. Basin efficiency in future years is assumed to increase at a prescribed rate in a basin, depending on water infrastructure investment and water management improvement in the basin.

The projection of irrigation water demand depends on the changes of irrigated area and cropping patterns, water use efficiency, and rainfall harvest technology. Global climate change can also affect future irrigation water demand through temperature and precipitation change, but was not considered in the original modeling framework.

#### II.A.b. Livestock Water Demand

Livestock water demand (*LVWD*) in the base year is estimated based on livestock numbers ( $QS_{lv}$ ) and water consumptive use per unit of livestock ( $w_{lv}$ ), including beef, milk, pork, poultry, eggs, sheep and goats, and aquaculture fish production. For all of the livestock products it is assumed that the projection of livestock water demand in each basin, country, or region follows the same growth rate of livestock production. Then livestock water demand was determined as a linear function of livestock production, assuming no change in consumptive water use per unit of livestock production

$$LVWD = QS_{lv} \cdot w_{lv} \quad (28)$$

#### II.A.c. Industrial Water Demand

Projection of industrial water demand depends on income (gross domestic production per capita (*GDPC*)) and water use technology improvement. A linear relationship between industrial water demand intensity (*IWDI* per cubic meter of water per \$1,000 *GDP*) and *GDP* per capita and a time variable (*T*) is estimated by regression based on historical records (Shiklomanov 1999 for industrial water consumption; World Bank 1998) and adjusted according to our perspectives on future industrial water demand in different regions and countries.

$$IWDI = \alpha + \beta \cdot GDPC + \gamma \cdot T \quad (29)$$

in which  $\alpha$  is the intercept;  $\beta$  is the income coefficient, reflecting how industrial water use intensity changes with *GDPC*; and  $\gamma$  is the time coefficient, mainly reflecting the change of water use

technology with technology change. It is found that  $\alpha > 0$ ,  $\partial IWDI / \partial GDPC = \beta < 0$ , and  $\partial IWDI / \partial T = \gamma < 0$  for all basins and countries, which shows that in future years, the industrial water use intensity will reduce with the *GDPC* and *T* ( $T = 95$  for 1995; 100 for 2000; and so on).

#### II.A.d. Domestic Water Demand

Domestic water demand (DOWD) includes municipal water demand and rural domestic water demand. Domestic water demand in the base year is estimated based on the same sources and methods as those used for industrial water demand assessment. Domestic water demands in future years are projected based on projections of population and income growth. In each country or basin, income elasticities ( $\eta$ ) of demand for domestic use are synthesized based on the literature and available estimates. These elasticities of demand measure the propensity to consume water with respect to increases in per capita income. The elasticities utilized are defined to capture both direct income effects and conservation of domestic water use through technological and management change. The annual growth rate of domestic water demand  $\phi_{dwd}$  is a function of the growth rate of population ( $\phi_{pop}$ ) and that of income (GDPC,  $\phi_{gdpc}$ ), as

$$\phi_{dwd} = \phi_{pop} + \eta \cdot \phi_{gdpc} \quad (30)$$

where  $\partial \phi_{dwd} / \partial \phi_{gdpc} = \eta < 0$  implies that per capita domestic water demand will actually decline with income growth, which occurs in some developed countries where current per capita domestic water consumption is high; and  $\partial \phi_{dwd} / \partial \phi_{gdpc} = \eta > 0$  implies that per capita domestic water demand increases with income growth, which occurs in all developing countries.

#### II.A.e. Committed Flow for Environmental, Ecological, and Navigational Uses

In the modeling framework, committed flow is specified as a percentage of average annual runoff. Data is lacking on this variable for most basins and countries, so an iterative procedure is used to specify this variable where data is lacking. The base value for committed flows is assumed to be 10 percent, with additional increments of 20–30 percent if navigation requirements are significant (for example, Yangtze River basin); 10–15 percent if environmental reservation is significant, as in most

developed countries; and 5–10 percent for arid and semi-arid regions where ecological requirements, such as salt leaching, are high (for example, Central Asia). The estimated values for committed flows are then calibrated for the base year relative to basin inflow, outflow, and consumptive use.

#### II.A.f. Demand for Water Withdrawals as Depletion

Off-stream water demand items described above are all expressed in water depletion/consumption terms. The demand for water withdrawal is calculated as total water depletion demand (DWP) divided by the water depletion coefficient:

$$DWW = DWP / DC = (IRWD + INWD + DOWD + LVWD) / DC \quad (31)$$

The value of the water depletion coefficient in the context of the river basin mainly depends on the relative fraction of agricultural and nonagricultural water use (that is, larger agricultural water use corresponds to a higher value of water depletion coefficient), as well as water conveyance/distribution/recycling systems and pollution discharge and treatment facilities. In the base year, DC is calculated by given water depletion (WDP) and water withdrawal (WITHD), and DC in the future is projected as a function of the fraction of non-irrigation water use:

$$DC = \rho \cdot \left( \frac{WDPDO + WDPIN + WDPLV}{WDPT} \right)^\psi \quad (32)$$

This regression function is made based on historical non-irrigation water depletion and total water depletion in different basins or countries, resulting in regression coefficients  $\rho > 0$ , and  $\psi < 0$  for all basins and countries.

#### II.A.g. Price Impact on Water Demand

A classic Cobb-Douglas function is used to specify the relationship between water demand ( $W$ ) and water price ( $P$ ), based on price elasticity ( $\xi$ ):

$$W = W_0 \cdot \left( \frac{P}{P_0} \right)^\xi \quad (33)$$

where  $W_0$  and  $P_0$  represent a baseline water demand and water price, respectively. This relationship is applied to agricultural, industrial, and domestic sectors, with price elasticity ( $\xi$ ) estimated for each of the sectors.

## II.B. Water Supply

Assuming minimum environmental and ecological flow requirements as a predetermined hard constraint in water supply, we focus on the determination of off-stream water supply for domestic, industrial, livestock, and irrigation sectors. Two steps are undertaken to determine off-stream water supply by sectors. The first is to determine the total water supply represented as depletion/consumption (WDP) in each month of a year; and the second is to allocate the total to different sectors. Particularly, irrigation water supply is further allocated to different crops in the basin.

To determine the total amount of water available for various off-stream uses in a basin, hydrologic processes, such as precipitation, evapotranspiration, and runoff are taken into account to assess total renewable water (TRW). Moreover, anthropogenic impacts are combined to define the fraction of the total renewable water that can be used. These impacts can be classified into (1) water demands; (2) flow regulation through storage, flow diversion, and groundwater pumping; (3) water pollution and other water losses (sinks); and (4) water allocation policies, such as committed flows for environmental purposes, or water transfers from agricultural to municipal and industrial uses. Therefore, water supply is calculated based on both hydrologic processes and anthropogenic impacts through the model, including the relationships listed above.

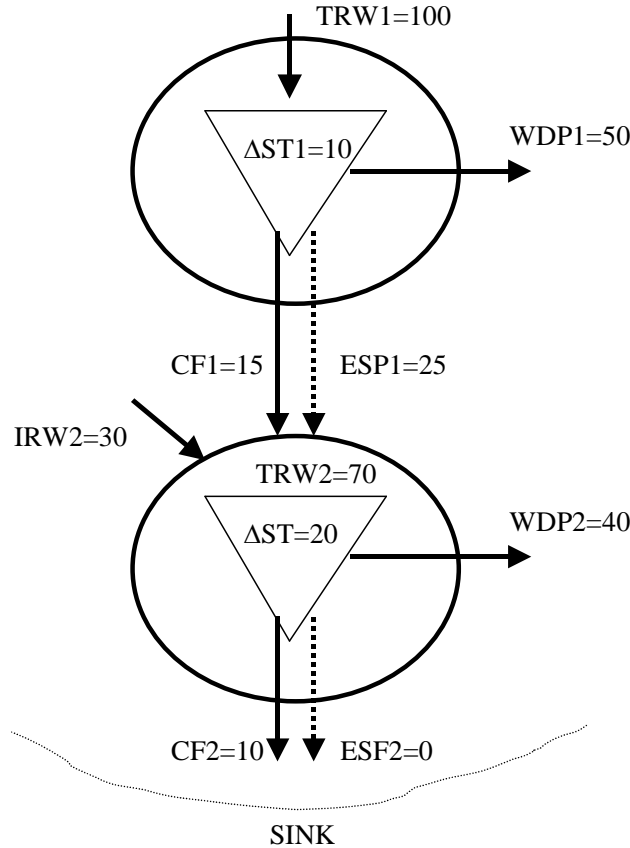
A simple network with a two-basin framework can be used as an example (Figure 2). Water availability in the downstream basin depends on the rainfall drainage in the basin and the inflow from the upstream basin(s). Then surface water balance at the basin scale can be represented as:

$$ST^t - ST^{t-1} = ROFF^t + INF^t + OS^t - SWDP^t - RL^t - EL^t \quad (34)$$

in which  $t$  is the modeling time interval;  $ST$  is the change of basin reservoir storage;  $INF$  is the inflow from other basin(s);  $OS$  represents other sources entering water supply system, such as water desalinated;  $RL$  is the total release, including the committed instream flow and spill in flooding periods;  $EL$  is the evaporation loss (mainly from surface reservoir surface); and  $SWDP$  is the total water depletion from surface water sources which is equal to water withdrawal minus return flow.  $SWDP$  is determined from this water balance equation, with an upper bound constrained by surface maximum allowed water withdrawal ( $SMAWW$ ) as:

$$\sum_t SWDP^t / DC \leq SMAWW \quad (35)$$

Other constraints related to the items in Equation 8 include that flow release ( $RL$ ) must be equal or greater than the committed instream flow; monthly reservoir evaporation is calculated based on reservoir surface area, and climate characteristics.



**Figure 2. Connected flow among river basins, countries, regions**

Source: Rosegrant et al. (2002)

Notes: TRW indicates total renewable water; IRW, internal renewable water; WDP; water consumption; CF, committed flow; ESP, excess spill; and ΔST, storage change.

Depletion from groundwater (GWDP) is constrained by maximum allowed water withdrawal from groundwater (GMAWW):

$$\sum_t GWDP^t / DC \leq GMAWW \quad (36)$$

The estimation of the  $SMAWW$  and  $GMAWW$  in the base year (1995) is based on the actual annual water withdrawal and annual groundwater pumping in 1995 (WRI 2000). Projections of

*SMAWW* and *GMAWW* are based on assumptions on future surface and ground water development in different countries and regions. In particular, the projection of *GMAWW* is based on historic pumping and potential groundwater sources (measured by groundwater recharge).

A traditional reservoir operation model is incorporated, including all of the above relationships of natural water availability, storage regulation, withdrawal capacity, and committed flow requirements. The model is formulated as an optimization model. The model is run for individual years with month as the time period. The objective is to maximize the reliability of water supply (that is, ratio of water supply over demand, less or equal to 1.0), as

$$\max \left[ \frac{\sum_t (SWDP^t + GWDP^t)}{\sum_t (DOWD^t + INWD^t + LVWD^t + IRWD^t)} + \omega \cdot \min_t \left( \frac{SWDP^t + GWDP^t}{DOWD^t + INWD^t + LVWD^t + IRWD^t} \right) \right] \quad (37)$$

and as can be seen, the objective function also drives the water application according to the water demand in crop growth stages (months) by maximizing the minimum ratio among time periods (12 months). The weight item  $\omega$  is determined by trial-and-error until water supply is distributed to months approximately proportional to monthly water demand.

Once the model solves for total water that could be depleted in each month ( $SWDP^t$  and  $GWDP^t$ ) for various off-stream uses under the constraints described above, the next step is to determine the water supply available for different sectors. Assuming domestic water demand is satisfied first, priority is then given to industrial and livestock water demand, whereas irrigation water supply is the residual claimant. Monthly non-irrigation water demands are calculated based on their annual value multiplied by monthly distribution coefficients. Water supply represented as depletion for different sectors is calculated as:

$$WDPDO^t = \min (DOWD^t, SWDP^t + GWDP^t) \quad (38)$$

$$WDPIN^t = \min (INWD^t, SWDP^t + GWDP^t - WDPDO^t) \quad (39)$$

$$WDPLV^t = \min (LVWD^t, SWDP^t + GWDP^t - WDPDO^t - WDPIN^t) \quad (40)$$

$$WDIR^t = \min (IRWD^t, SWDP^t + GWDP^t - WDPDO^t - WDPIN^t - WDPLV^t) \quad (41)$$

Finally, total water available for crop evapotranspiration ( $NIW$ ) is calculated by introducing the basin efficiency ( $BE$ ) for irrigation systems and discounting the salinity leaching requirements, as

$$TNIW^t = BE \cdot WDIR^t / (1 + LR) \quad (42)$$

$TET$  can be further allocated to crops according to crop irrigation water demand, yield response to water stress ( $ky$ ), and average crop price ( $P_c$ ) for each of the major crops considered in a basin, including rice, wheat, maize, other grains, soybeans, potato, sweet potato, and roots and tubers.

The allocation fraction is defined as:

$$\pi^{i,t} = \frac{ALLO^{i,t}}{\sum_{cp} ALLO^{i,t}} \text{ and,} \quad (43)$$

$$ALLO^i = AI^i \cdot ky^i \cdot [1 - PE^{i,t} / ETM^{i,t}] \cdot PC^i \quad (44)$$

in which  $ETM^{cp,t} = ET_0^{cp,t} \cdot kc^{cp,t}$ , is the maximum crop evapotranspiration;  $\pi$  is a scaled number in the range of (0,1) and the sum of  $\pi$  over all crops is set to equal 1. The effective water supply allocated to each crop is then calculated by

$$NIW^{i,t} = TNIW^t \cdot \pi^{i,t} \quad (45)$$

Thus, irrigation water is allocated based on profitability of the crop, sensitivity to water stress, and irrigation water demand (total demand minus effective rainfall) of the crop. Higher priority is given to the crops with higher profitability, which are more drought sensitive, and/or that require more irrigation water.

### II.C. Effective Rainfall

Effective rainfall ( $PE$ ) depends on total rainfall ( $PT$ ), previous soil moisture content ( $SM0$ ), maximum crop evapotranspiration ( $ETM$ ), and soil characteristics (hydraulic conductivity  $K$ , moisture content at field capacity  $Z_s$ , and others).  $PE$  is calculated by an SCS method (USDA, SCS 1967), given  $PT$ ,  $ETM$ , and effective soil water storage:

$$PE^{cp,st} = f \cdot \left( 1.253PT^{st 0.824} - 2.935 \right) \cdot 10^{(0.001ETM^{cp,st})} \quad (46)$$

in which  $f$  is the correction factor that depends on the depth of irrigation, that is,

$$f = 1.0 \text{ if depth of irrigation per application, } DI, \text{ is } 75\text{mm,} \quad (47)$$

$$f = 0.133 + 0.201 \cdot \ln(Da) \text{ if } DI < 75\text{mm per application, and} \quad (48)$$

$$f = 0.946 + 0.00073 \cdot Da \text{ if } DI > 75\text{mm per application.} \quad (49)$$

Depth of irrigation application is 75mm to 100mm for irrigated land, and 150mm to 200mm for rainfed land. If the above results in  $PE$  greater than  $ET_m$  or  $PT$ ,  $PE$  equals the minimum of  $ET_m$  or  $PT$ . When  $PT < 12.5\text{mm}$ ,  $PE = PT$ .

Global precipitation grids (half degree) (1961–90, monthly data) from the University of East Anglia are used to extract the total rainfall on the cropland in the regions/countries/basins from the Food side (Box A1). With crop-wise  $ET_m$  and total rainfall, crop-wise monthly effective rainfall (time series over 30 years) is calculated by the SCS method described above.

Moreover, the effective rainfall for crop growth can be increased through rainfall harvesting technology. Rainfall harvesting is the capture, diversion, and storage of rainwater for plant irrigation and other uses, and can be an effective water conservation tool, especially in arid and semi-arid regions. Water harvesting can provide farmers with improved water availability, increased soil fertility, and higher crop production in some local and regional ecosystems, and can also provide broader environmental benefits through reduced soil erosion. Advanced tillage practices can also increase the share of rainfall that goes to infiltration and evapotranspiration. Contour plowing, which is typically a soil-preserving technique, should also act to detain and infiltrate a higher share of the precipitation. Precision leveling can also lead to greater relative infiltration, and therefore a higher percentage of effective rainfall. A coefficient ( $\lambda$ ,  $\lambda > 1$ ) is used to reflect the addition of effective rainfall from rainfall harvesting at various levels,

$$PE^{*cp,st} = \lambda \cdot PE^{cp,st} \quad (50)$$

### III. Model Implementation

The model implementation procedure is shown in Box 1. The model is applied for a monthly water balance within one year. It is run through a series of years by solving individual years in sequence and connecting the outputs from year to year. The time series of climate parameters are derived based on 30-years of historical records, 1961–90. In addition to a basic scenario that overlays the single historic time series over the 1995–2025 projection period, a number of scenarios of hydrologic time series can be generated by changing the sequence of the yearly records. Water supply uncertainty from various hydrologic levels can then be identified from the statistics of multiple hydrologic scenarios.

#### Box 1. Model implementation procedure

**Base Year** (*such as 2000*)

For each **group  $i$**  of (group1 .. group5)

    For each individual/aggregated **basin  $j$**  in **group  $i$**

        Given water demand and supply parameters in the base year

        (Including estimated initial reservoir storage and external inflow)

        Solve WSM for water supply

        Calculate outflow from **basin  $j$**

    End of **group  $i$**

End of all groups

**Projected years** (*such as 2001–2050*)

For each **year  $k$**  of (2001 –2050)

    For each **group  $i$**  of (group1 .. group5)

        For each individual/aggregated **basin  $j$**  in **group  $i$**

            Update water demand and supply parameters, including initial reservoir storage from the end of *year  $k-1$* , and inflow from other units in the groups previously solved (for group 1, inflow is equal to 0)

            Solve WSM for water supply

            Calculate outflow **basin  $j$**

        End of **group  $i$**

    End of all groups in **year  $k$**

End of all years

Source: Rosegrant et al. (2002).

The end-year storage of one year is taken as the initial storage of the following year, with assumed initial water storage for the base year. For those basins that have large storage, inter-year flow regulation is active in this modeling framework. Water demand for non-irrigation sectors (*LVWD*, *IWDI*, *DOWD*) is updated year by year (Equations 28-30). Infrastructure is updated by projections of reservoir storage, water use efficiency, and maximum allowed water withdrawal (*MAWW*).

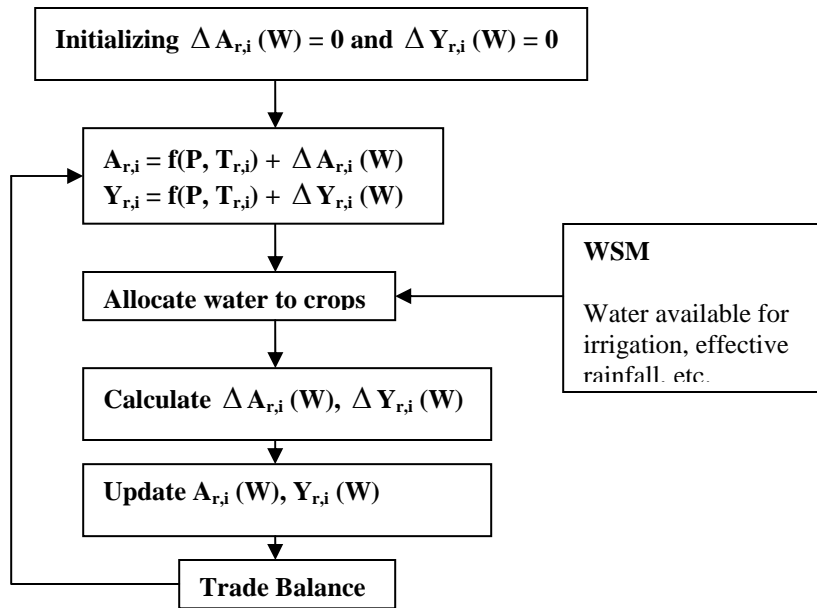
The model is run for individual basins, but with simulation of transboundary basins. The outflow (*RL*) from one basin can be the source of downstream basins, which is important for many international river basins such as the Nile (Sudan, Ethiopia, Egypt, Uganda, Burundi, Tanzania, Kenya, Zaire, and Rwanda); the Mekong (China, Laos, Burma, Thailand, Cambodia, and Viet Nam); the Indus (Pakistan, India, Afghanistan, and China); the Ganges-Brahmaputra (China, India, Bangladesh, Bhutan, and Nepal); the Amazon (Brazil, Peru, Bolivia, Colombia, Ecuador, Venezuela, and Guyana); the Danube (Romania, Yugoslavia, Hungary, Albania, Italy, Austria, Czechoslovakia, Germany, Russia, Poland, Bulgaria, and Switzerland); the Niger (Mali, Nigeria, Niger, Algeria, Guinea, Chad, Cameroon, Burkina Faso, Benin, Cote D'Ivoire); the Tigris-Euphrates (Iraq, Iran, Turkey, and Syria); and the Rio Grande (United States and Mexico). The river basins used in the model are described in more detail in Appendix 4.

#### **IV. Connecting the Food and Water Components**

The water component calculates effective irrigation water supply in each basin by crop and by period ( $NIW^i_t$ ), over a 30-year time horizon. The results are then incorporated in simulating food production, demand, and trade.

Figure 3 shows the flow chart of the combined food and water system. For each year, initially, it is assumed that there is no water shortage,  $\Delta AC(W)$  and  $\Delta YC(W)$  are zero, and crop area harvested and crop yields are determined based on price, labor, fertilizer, and other inputs, and technological change. Then water availability for crops is computed,  $\Delta AC(W)$  and  $\Delta YC(W)$  are calculated, and crop area (*A*) and yield (*Y*) are updated. Next, crop production and stock are updated, and net food trade and the global trade balance calculated (global net trade should equal zero). If the trade balance is violated, then crop prices are adjusted, and the model undertakes a new iteration. The loop stops when net trade equals zero. Thus, crop area and yield are determined endogenously

based on water availability, price, and other agricultural inputs.



**Figure 3. Flow chart of the IMPACT-WATER program**

Source: Rosegrant et al. (2002).

## REFERENCES

- ACC/SCN (United Nations Administrative Committee on Coordination–Subcommittee on Nutrition). 1992. *Second Report on the World Nutrition Situation. Volume I.* Geneva: ACC/SCN.
- \_\_\_\_\_. 1996. *Update on the Nutrition Situation, 1996.* Geneva: United Nations Administrative Committee on Coordination–Subcommittee on Nutrition.
- Delgado, C. L., N. Wada, M.W. Rosegrant, S. Meijer, and M. Ahmed. 2003. *Fish to 2020: Supply and Demand in Changing Global Markets.* World Fish Center Technical Report no. 62. Washington, D.C.: International Food Policy Research Institute.
- Delgado, C. L., M.W. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. *Livestock to 2020. The Next Food Revolution.* 2020 Vision Discussion Paper 28. Washington, D.C.: International Food Policy Research Institute.
- Evenson, R. E., and M.W. Rosegrant. 1995. *Productivity Projections for Commodity Marketing Modeling.* Paper presented at the Final Workshop of the International Cooperative Research Project on "Projections and Policy Implications of Medium and Long-Term Rice Supply and Demand", organized by IFPRI, IRRI, and CCER, Beijing, China, April 23-26, 1995.
- Ingo, M. and F. Ng. 1998. *Distortionary Effects of State Trading in Agriculture: Issues for the Next Round of Multilateral Trade Negotiations.* Washington, D.C.: World Bank.
- Fan, S. and F. Tuan. 1998. *Evolution of Chinese and OECD Agricultural Policy: Long-term Lessons for China.* Paper prepared for the Workshop Agricultural policies in China and OECD countries: Review, outlook and challenges, organized by the OECD Directorate for Food, Agriculture and Fisheries, 19-20 November 1998, OECD Headquarters, Paris.
- FAO (Food and Agriculture Organization). 2000a. *FAOSTAT database.* Accessible via FAO home page at <http://apps.fao.org/>.
- \_\_\_\_\_. 2000b. *Food Outlook, Global information and early warning system on food and agriculture, Commodities and Trade Division (ESC), Rome, Italy.*
- \_\_\_\_\_. 1998. *FAOSTAT database.* Accessible via FAO home page at <http://apps.fao.org/>.
- Finger, J.M; M.D. Ingo; and U. Reincke. 1996. *The Uruguay Round: Statistics on Tariff Concessions Given and Received.* Washington, D.C.: World Bank
- von Lampe, M. 2006. *Agricultural Market Impacts of Future Growth in the Production of Biofuels.* Report of the Working Party on Agricultural Policies and Markets, Organization for Economic Cooperation and Development (OECD), Paris.

- MA (Millennium Ecosystem Assessment). 2005. *Ecosystems and Human Well-Being: General Synthesis* (Millennium Ecosystem Assessment Series). Washington, D.C.: Island Press. <http://www.millenniumassessment.org/documents/document.356.aspx.pdf>
- McDougall, R.A.; A. Elbehri; and T.P. Truong. 1998. *Global Trade Assistance and Protection: The GTAP 4 Data Base*. Purdue University: Center for Global Trade Analysis
- Smith, L. and L. Haddad. 2000. *Explaining Child Malnutrition in Developing Countries: A Cross-Country Analysis*. IFPRI Research Report. IFPRI: Washington, DC.
- Rosegrant, M.W., X. Cai, and S.A. Cline. 2002. *World Water and Food to 2025*. Washington D.C., International Food Policy Research Institute.
- Rosegrant, M.W., M.S.Paisner, S. Meijer and J. Witcover. 2001. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. 2020 Vision Food Policy Report. Washington D.C., International Food Policy Research Institute.
- Rosegrant, M.W. and P.B.R. Hazell. 2000. *Transforming the Rural Asian Economy: The Unfinished Revolution*. Oxford University Press: Hong Kong.
- Rosegrant, M.W. and C. Ringler. 2000. Asian Economic Crisis and the Long-Term Global Food Situation. *Food Policy* 25(3): 243-254.
- Rosegrant, M.W., C.F. Runge and X. Cai. 2000. Modeling Water Availability and Food Security: A North American Application of the IMPACT-WATER Model. *Study prepared for the North American Commission for Environmental Cooperation* Washington D.C., International Food Policy Research Institute.
- Rosegrant, M.W., N. Leach, and R.V. Gerpacio. 1999. Alternative futures for world cereal and meat consumption. *Proceedings for the Nutrition Society* 58(2): 219-234.
- Rosegrant, M.W., M.C. Agcaoili-Sombilla and N. Perez. 1995. *Global Food Projections to 2020: Implications Investment*. 2020 Vision Discussion Paper 5. Washington D.C., International Food Policy Research Institute.
- Scott, G., M.W. Rosegrant, and C. Ringler 2000. *Roots and Tubers for the 21st Century: Trends, Projections, and Policy Options*. 2020 Vision Discussion Paper 31. Washington, D.C.: International Food Policy Research Institute.
- UN (United Nations). 1998. *World population prospects: 1998 revisions*. New York: United Nations.
- UNCTAD (United Nations Conference on Trade and Development). Various years. *Handbook of International Trade and Development Statistics*. Geneva: United Nations Conference on Trade and Development.

- UNESCO (United Nations Educational Scientific and Cultural Organization). 1998. *UNESCOSTAT Database*. Accessible at <http://unescostat.unesco.org>.
- USDA (United States Department of Agriculture). 2000a. Data obtained from the Economic Research Service's (ERS) Foreign Agricultural Trade of the United States database. Accessible at <http://www.ers.usda.gov/Data/FATUS/>.
- USDA (United States Department of Agriculture). 2000b. *Milk Production, Disposition and Income; 1999 Summary*. National Agricultural Statistics Service (NASS), USDA, USA.
- Valdes, R. 1996. *Surveillance of agricultural price and trade policy in Latin America during major policy reforms*. World Bank Discussion Paper No. 349. Washington, DC: World Bank.
- Valdés, A. and B. Schaeffer. 1995a. *Surveillance of agricultural price and trade policies: a handbook for Argentina*. World Bank Technical Paper No. 294. Washington, DC: World Bank.
- \_\_\_\_\_. 1995b. *Surveillance of agricultural price and trade policies: a handbook for Chile*. World Bank Technical Paper No. 291. Washington, DC: World Bank.
- \_\_\_\_\_. 1995c. *Surveillance of agricultural price and trade policies: a handbook for Colombia*. World Bank Technical Paper No. 268. Washington, DC: World Bank.
- \_\_\_\_\_. 1995d. *Surveillance of agricultural price and trade policies: a handbook for Dominican Republic*. World Bank Technical Paper No. 267. Washington, DC: World Bank.
- WHO (World Health Organization). 1997. *WHO Global Database on Child Growth and Malnutrition*. Programme of Nutrition. WHO Document #WHO/NUT/97.4. Geneva: World Health Organization.
- World Bank. 2000. *Global Commodity Markets: A Comprehensive Review and Price Forecast*. Developments Prospects Group, Commodities Team. Washington D.C.: The World Bank
- \_\_\_\_\_. 1998. *World Development Indicators on CD-Rom*. Washington, D.C.: The World Bank.
- \_\_\_\_\_. 1997. *World Development Indicators on CD-Rom*. Washington, D.C.: The World Bank.

## APPENDIX 1: CITED WORKS WITH IMPACT

- Agcaoili-Sombilla, M. and M.W. Rosegrant. 1994. World Supply and Demand Projections for Cereals, 2020. 2020 Brief No. 2. Washington, D.C.: International Food Policy Research Institute.
- Bradford, E., R. Lee Baldwin, H. Blackburn, K.G. Cassman, P.R. Crosson, C.L. Delgado, J.G. Fadel, H.A. Fitzhugh, M. Gill, J.W. Oltjen, M.W. Rosegrant, M. Vavra, R.O. Wilson. 1999. Animal Agriculture and Global Food Supply. Task Force Report No. 135. Iowa, USA: Council for Agricultural Science and Technology.
- Carruthers, I., M.W. Rosegrant, and D. Seckler. 1997. Irrigation and Food Security in the 21st Century. *Irrigation and Drainage Systems* 11(2)(May): 83-101.
- Delgado, C. L., M.W. Rosegrant, and S. Meijer. 2001. Livestock to 2020: The Revolution Continues. Paper presented at the annual meetings of the International Agricultural Trade Research Consortium (IATRC), Auckland, New Zealand, January 18-19, 2001.
- Delgado, C., M.W. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 2000. Livestock to 2020: The next food revolution. International Meat Secretariat Newsletter, No. 24, January 2000.
- Delgado, C. L., M.W. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. Livestock to 2020. The Next Food REvolution. 2020 Vision for Food, Agriculture, and the Environment. Discussion Paper No. 28. Washington, D.C.: International Food Policy Research Institute.
- Delgado C., M.W. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. The Coming Livestock Revolution. Special millennium issue of *Choices* (fourth quarter 1999).
- Evenson, R. E., C. Pray, and M.W. Rosegrant. 1999. *Agricultural Research and Productivity Growth in India*. IFPRI Research Report No. 109. Washington, D.C.: International Food Policy Research Institute.
- Evenson, R. E., and M.W. Rosegrant. 1995. Productivity Projections for Commodity Marketing Modeling. Paper presented at the final workshop of the International Cooperative Research Project on "Projections and Policy Implications of Medium and Long-Term Rice Supply and Demand", organized by IFPRI, IRRI, and CCER, Beijing, China, April 23-26, 1995.
- Huang, J., S. Rozelle, and M.W. Rosegrant. 1999. China's Food Economy to the 21st Century. *Economic Development and Cultural Change* 47(4): 737-766.
- Huang, J., S. Rozelle, and M.W. Rosegrant. 1997. *China's food economy to the twenty-first century: Supply, demand, and trade*. IFPRI 2020 Vision for Food, Agriculture, and the Environment Discussion Paper No. 19 (January). Washington, D.C.: International Food Policy Research Institute.

- McKinney, D.C., X. Cai, M. Rosegrant, C. Ringler, C.A. Scott. 2000. Integrated Basin-Scale Water Resources Management Modeling: Review and Future Directions. *Agricultural Economics* 24(1): 33-46.
- Pandya-Lorch, R., P. Pinstруп-Andersen, and M.W. Rosegrant. 2001. Prospects for food demand and supply towards 2020. Paper presented to the International Fertilizer Society at a Symposium in Lisbon, March 4.
- Pandya-Lorch, R. and M.W. Rosegrant. 2000. Prospects for Food Demand and Supply in Central Asia. *Food Policy* 25(6): 637-646.
- Pandya-Lorch, R. and M.W. Rosegrant. 1999. World Food in the Twenty-First Century. Special millennium issue of *CHOICES* (fourth quarter 1999).
- Pinstруп-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant. 2000. World Food Prospects. *Agrarwirtschaft* 49(9/10). September special issue "Meeting the Food Challenge of the Twenty-First Century".
- Pinstруп-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant. 1999. *World Food Prospects: Critical Issues for the Early Twenty-first Century*. Food Policy Report No. 29. Washington, D.C.: International Food Policy Research Institute.
- Pinstруп-Andersen, P.; R. Pandya-Lorch, Rajul, M.W. Rosegrant, and F. Peterson. 1999. *World Food Prospects: Critical Issues for the Early Twenty-First Century*. Food Policy Report. Washington, D.C.: International Food Policy Research Institute.
- Pinstруп-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant. 1997. The World Food Situation: Recent Developments, Emerging Issues, and Long-Term Prospects. Food Policy Report. Washington, D.C.: International Food Policy Research Institute.
- Rosegrant M. W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. Washington D.C.: International Food Policy Research Institute.
- Rosegrant M. W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. *2020 Global Food Outlook: Trends and Alternative Futures*. IFPRI Food Policy Report. Washington D.C.: International Food Policy Research Institute.
- Rosegrant, M.W., M.S. Paisner, and C. Ringler. 2001. Global and Southeast Asian trends in food supply, demand, and food security. Paper presented at the World Food Program conference, "The role of Food Aid in Cambodia," February 8-9, Phnom Penh.

- Rosegrant, M.W., M.S. Paisner, and S. Meijer. 2001. Long-term perspectives on the change of major agricultural and resource base variables. Background Paper prepared for the World Bank's "Vision to Action".
- Rosegrant, M.W. and X. Cai. 2001. Water Scarcity and Food Security: Alternative Futures for the 21st Century. *Journal of Water Science and Technology* 43(4): 61-70.
- Rosegrant, M.W. and C. Ringler. 2000. Asian Economic Crisis and the Long-Term Global Food Situation. *Food Policy* 25(3): 243-254.
- Rosegrant, M.W., C. Ringler, D. C. McKinney, X. Cai, A. Keller, and G. Donoso. 2000. Integrated Economic-hydrologic Water Modeling at the Basin Scale: The Maipo River Basin. *Agricultural Economics* 24(1): 33-46.
- Rosegrant, M.W., M. S. Paisner, and C. Ringler. 2000. Agricultural research, technology and world food markets. Paper presented at the 2000 IAAE Conference, August 11-17, Berlin.
- Rosegrant, M.W. and P. B. R. Hazell. 2000. *Transforming the Rural Asian Economy: The Unfinished Revolution*. Hong Kong: Oxford University Press.
- Rosegrant, M.W. and C. Ringler. 1999. World Water Vision Scenarios: Consequences for food supply, demand, trade, and food security: Results from the IMPACT implementation of the World Water Vision Scenarios, Paper prepared for the Scenario Development Panel of the World Commission on Water for the 21st Century, Forthcoming, Second World Water Forum, Scenario Vision Proceedings.
- Rosegrant, M.W., N. Leach, and R.V. Gerpacio. 1999. Alternative futures for world cereal and meat consumption. *Proceedings for the Nutrition Society* 58(2): 219-234.
- Rosegrant, M.W., and C. Ringler. 1998. Impact on Food Security and Rural Development of Transferring Water out of Agriculture. *Water Policy* 1(6): 567-586.
- Rosegrant, M.W. and C. Ringler. 1997. World Food Markets into the 21st Century: Environmental and Resource Constraints and Policies. *The Australian Journal of Agricultural and Resource Economics*. 41(3): 401-428.
- Rosegrant, M.W., C. Ringler, and R. Gerpacio. 1999. Water and Land Resources and Global Supply. In *Food Security, Diversification and Resource Management: Refocusing the Role of Agriculture*, ed. G.H. Peters and J. von Braun. Proceedings of the 23rd International conference of Agricultural Economics held at Sacramento, California 10-16 August 1997. England: University of Oxford.
- Rosegrant, M.W. and M.C. Agcaoili-Sombilla. 1996. South Asia and the Global Food Situation: Challenges for Strengthening Food Security. *Journal of Asian Economics* 7(2): 265-292.
- Rosegrant, M.W. 1996. *Global Food Supply and Demand: the Impact on People, Politics and*

*Prices*. Canberra: Crawford Fund for International Agricultural Research.

Rosegrant, M.W., M. Agcaoili-Sombilla, and N.D. Perez. 1995. *Global Food Projections to 2020: Implications for Investment*. 2020 Discussion Paper No. 5. Washington, D.C.: International Food Policy Research Institute.

Rozelle, S. and M.W. Rosegrant. 1997. China's Past, Present, and Future Food Economy: Can China Continue to Meet the Challenges? *Food Policy* 22(3)(June): 191-200.

San, N.N. and M.W. Rosegrant. 1998. Indonesian agriculture in transition: Projections of alternative futures. *Journal of Asian Economics* 9(3): 445-65.

Scott, G., M.W. Rosegrant, and C. Ringler. 2000. *Roots and Tubers for the 21st Century: Trends, Projections, and Policy Options*. 2020 Vision Discussion Paper 31. Washington, D.C.: International Food Policy Research Institute.

Scott, G.J., M.W. Rosegrant, and C. Ringler. 2000. *Roots and Tubers for the 21st Century*. 2020 Discussion Paper No. 31. Washington, D.C.: International Food Policy Research Institute.

Scott, G. J., M.W. Rosegrant, and C. Ringler. 2000. Global Projections for Root and Tuber Crops to the Year 2000. *Food Policy* 25(5): 561-597.

## APPENDIX 2: IMPACT COUNTRIES/REGIONS, AND COMMODITIES

<b>Countries &amp; Regions</b>			
		43	Guinea-Bissau
1	Adriatic	44	Gulf
2	Afghanistan	45	Iberia
3	Algeria	46	India
4	Alps	47	Indonesia
5	Angola	48	Iran
6	Argentina	49	Iraq
7	Australia	50	Israel
8	Baltic	51	Italy
9	Bangladesh	52	Ivory Coast
10	Belgium-Luxembourg	53	Japan
11	Benin	54	Jordan
12	Bhutan	55	Kazakhstan
13	Botswana	56	Kenya
14	Brazil	57	Kyrgyzstan
15	British Isles	58	Lebanon
16	Burkina-Faso	59	Lesotho
17	Burundi	60	Liberia
18	Cameroon	61	Libya
19	Canada	62	Madagascar
20	Caribbean-Central America	63	Malawi
21	Caucasus	64	Malaysia
22	Central-African Republic	65	Mali
23	Central-Europe	66	Mauritania
24	Central South-America	67	Mexico
25	Chad	68	Mongolia
26	Chile	69	Morocco
27	China	70	Mozambique
28	Colombia	71	Myanmar
29	Congo	72	Namibia
30	Cyprus	73	Nepal
31	Djibouti	74	Netherlands
32	Ecuador	75	New Zealand
33	Egypt	76	Niger
34	Equatorial-Guinea	77	Nigeria
35	Eritrea	78	North Korea
36	Ethiopia	79	Northern South-America
37	France	80	Pakistan
38	Gabon	81	Papua-New Guinea
39	Gambia	82	Peru
40	Germany	83	Philippines
41	Ghana	84	Poland
42	Guinea	85	Rest of the World

- 86 Russia
- 87 Rwanda
- 88 Scandinavia
- 89 Senegal
- 90 Sierra Leone
- 91 Singapore
- 92 Somalia
- 93 South Africa
- 94 South Korea
- 95 Southeast Asia
- 96 Sri Lanka
- 97 Sudan
- 98 Swaziland
- 99 Syria
- 100 Tajikistan
- 101 Tanzania
- 102 Thailand
- 103 Togo
- 104 Tunisia
- 105 Turkey
- 106 Turkmenistan
- 107 Uganda
- 108 Ukraine
- 109 United States
- 110 Uruguay
- 111 Uzbekistan
- 112 Vietnam
- 113 Democratic Republic of Congo
- 114 Zambia
- 115 Zimbabwe

**Commodities**

- 1. Beef
- 2. Pork
- 3. Sheep & Goat
- 4. Poultry

- 5. Eggs
- 6. Dairy
- 7. Wheat
- 8. Rice
- 9. Maize
- 10. Other Grains
- 11. Potatoes
- 12. Sweet Potatoes & Yams
- 13. Cassava and Other Roots & Tubers
- 14. Soybean
- 15. Meals
- 16. Oils
- 17. Vegetables
- 18. Sub-Tropical & Tropical Fruits
- 19. Temperate Fruits
- 20. Sugar Cane
- 21. Sugar Beets
- 22. Sweeteners
- 23. High Value Fish Aquaculture
- 24. High Value Fish Capture
- 25. High Value Other Aquaculture
- 26. High Value Other Capture
- 27. High Value Crustaceans  
Aquaculture
- 28. High Value Crustaceans Capture
- 29. Low Value Fish Aquaculture
- 30. Low Value Fish Capture
- 31. Fish Meal
- 32. Fish Oil
- 33. Sorghum
- 34. Millet
- 35. Chickpea
- 36. Pigeonpea
- 37. Groundnut
- 38. Cotton

### APPENDIX 3: DEFINITIONS OF WATER BASINS

1	Amazon	44	India East Coast
2	Amudarja	45	Indonesia East
3	Amur	46	Indonesia West
4	Arabian Peninsula	47	Indus
5	Arkansas	48	Ireland
6	Baltic	49	Italy
7	Black Sea	50	Japan
8	Borneo	51	Kalahari
9	Brahmaputra	52	Krishna
10	Brahmari	53	Lake Balkhash
11	Britain	54	Lake Chad Basin
12	California	55	Langcang Jiang
13	Canada-Arctic-Atlantic	56	Limpopo
14	Caribbean	57	Loire-Bourdeaux
15	Cauvery	58	Lower Mongolia
16	Central African West Coast	59	Luni
17	Central America	60	Madagascar
18	Central Australia	61	Mahi Tapti
19	Central Canada Slave Basin	62	Mekong
20	Chang Jiang	63	Middle Mexico
21	Chotanagpul	64	Mississippi
22	Colorado	65	Missouri
23	Columbia	66	Murray Australia
24	Columbia Ecuador	67	New Zealand
25	Congo	68	Niger
26	Cuba	69	Nile
27	Danube	70	North African Coast
28	Dnieper	71	North Euro Russia
29	East African Coast	72	North Korea Peninsula
30	Eastern Ghats	73	North South America
31	Eastern Australia Tasmania	74	Northeast Brazil
32	Eastern Mediterranean	75	Northwest Africa
33	Elbe	76	Northwest South America
34	Ganges	77	Ob
35	Godavari	78	Oder
36	Great Basin	79	Ohio
37	Great Lakes	80	Orange
38	Hai He	81	Orinoco
39	Horn of Africa	82	Papua Oceania
40	Hua He	83	Parana
41	Huang He	84	Peru Coastal
42	Iberia East Mediterranean	85	Philippines
43	Iberia West Atlantic	86	Red-Winnipeg

87	Rhine
88	Rhone
89	Rio Colorado
90	Rio Grande
91	Rest-of-World (ROW)
92	Sahara
93	Sahyada
94	Salada Tierra
95	San Francisco
96	Scandinavia
97	SE Asia Coast
98	Seine
99	Senegal
100	Songhua
101	South African Coast
102	South Korean Peninsula
103	Southeast African Coast
104	Southeast US
105	Sri Lanka
106	Syrdarja
107	Thai-Myan-Malay
108	Tierra
109	Tigris-Euphrates
110	Toc
111	Upper Mexico
112	Upper Mongolia
113	Ural
114	Uruguay
115	US Northeast
116	Volga
117	Volta
118	West African Coastal
119	Western Asia-Iran
120	Western Australia
121	Western Gulf Mexico
122	Yenisey
123	Yili He
124	Yucatan
125	Zambezi
126	Zhu Jiang

## **APPENDIX 4: DEFINITIONS OF IMPACT COMMODITIES**

### **Livestock**

#### **Meat**

1. Beef: beef and veal (Meat of bovine animals, fresh, chilled or frozen, with bone in) and buffalo meat (Fresh, chilled or frozen, with bone in or boneless).
2. Pork: pig meat (Meat, with the bone in, of domestic or wild pigs, whether fresh, chilled or frozen).
3. Poultry: chicken meat (Fresh, chilled or frozen. May include all types of poultry meat like duck, goose and turkey if national statistics do not report separate data).
4. Sheep and goat: (Meat of sheep and lamb, whether fresh, chilled or frozen, with bone in or boneless, and meat of goats and kids, whether fresh, chilled or frozen, with bone in or boneless).

#### **Other Livestock Products**

5. Eggs: (Weight in shell).
6. Milk: Cow, sheep, goat, buffalo and camel milk (Production data refer to raw milk containing all its constituents. Trade data normally cover milk from any animal, and refer to milk that is not concentrated, pasteurized, sterilized or otherwise preserved, homogenized or peptonized.).

### **Fish**

7. Low-value finfish: Carps, barbals and other cyprinids; Herrings, sardines, anchovies, jacks, mullets, sauries, mackarel, snoeks, cutlassfish; tilapias and other cichlids; river eels, shads; miscellaneous freshwater fishes; miscellaneous diadromous fishes; miscellaneous marine fishes<sup>1</sup>.
8. High-value finfish: Cods, hakes, haddocks, flounders, halibut, soles, redfishes, basses, confers, salmon, trout, smelts, shanks, rays, chimaeras, sturgeons, paddlefishes, tunas, bonitos, bullfishes.
9. Crustaceans: freshwater crustaceans, horseshoecrabs and other arachnoids; lobsters, spiny rock lobsters; miscellaneous marine crustaceans; sea-spiders, crabs, shrimp, prawns, squat-lobsters.
10. Mollusks: Abalones, winkles, conchs, clams, cockles, arkshells, freshwater mollusks, mussels, oysters, scallps, pectens, squids, cuttlefishes, octopuses, miscellaneous marine mollusks.
11. Fish meal and Fish Oil

### **Crops**

#### **Grains**

12. Maize: (Used largely for animal feed and commercial starch production).
13. Sorghum: (A cereal that has both food and feed uses).
14. Millet: (Used locally, both as a food and as a livestock feed).

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<sup>1</sup> These classifications follow ISCAAP categorizations. See Delgado et al., 2003

15. Other coarse grains: barley (Varieties include with husk and without. Used as a livestock feed, for malt and for preparing foods.), oats (Used primarily in breakfast foods. Makes excellent fodder for horses.), rye (Mainly used in making bread, whisky and beer. When fed to livestock, it is generally mixed with other grains).
16. Rice: Rice milled equivalent (White rice milled from locally grown paddy. Includes semi-milled, whole-milled and parboiled rice).
17. Wheat: (Used mainly for human food).

#### Roots and Tubers

18. Cassava et al.: Cassava and other tubers, roots or rhizomes. (Cassava is the staple food in many tropical countries. It is not traded internationally in its fresh state because tubers deteriorate very rapidly).
19. Potatoes: (Mainly used for human food).
20. Sweet potatoes and yams: Sweet potatoes (Used mainly for human food. Trade data cover fresh and dried tubers, whether or not sliced or in the form of pellets) and yams (A starchy staple foodstuff, normally eaten as a vegetable, boiled, baked or fried).

#### Vegetables

21. Onions, Tomatoes, miscellaneous vegetables.

#### Fruits

22. Temperate Fruits: Apples, grapes and miscellaneous temperate fruits.
23. Tropical and Sub-tropical Fruits: Bananas, Canteloupes & other melons, citrus fruits, dates, grapefruit, lemons, limes, oranges, pineapples, plantains, watermelons, miscellaneous tropical fruits.

#### Dryland Pulses

24. Chickpeas.
25. Pigeonpeas.

#### Other

27. Meals: copra cake, cottonseed cake, groundnut cake, other oilseed cakes, palm kernel cake, rape and mustard seed cake, sesame seed cake, soybean cake, sunflower seed cake, meat and blood meal (Residue from oil extraction, mainly used for feed).
28. Oils: vegetable oils and products, animal fats and products (Obtained by pressure or solvent extraction. Used mainly for food).
29. Soybeans: The most important oil crop (oil of soybeans under oils), but also widely consumed as a bean and in the form of various derived products because of its high protein content, e.g. soya milk, meat, etc.
30. Groundnuts
31. Cotton

*Source: FAO, 2000a, Delgado et al, 2003*

## APPENDIX 5: SCHEMATIC PRESENTATION OF IMPACT

