International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Distributed Version 1.0

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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 effect 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 trigged 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). The IMPACT model deployed with this internet-distribution most closely resembles that used in the Fish to 2020 analysis; the only difference being the countries and regional aggregations used as the spatial entities in the model.

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.

The next section presents the 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 detailed definitions of the countries and regions are shown in Appendices 3 and 4. After a description of the commodities, in Appendix 5, a schematic overview of the integrated modeling framework is given in Appendix 6.

THE MODEL

Technical *IMPACT* Methodology

Encompassing countries and regions in the world and the main agricultural commodities produced in the world (see Appendices 2, 3, and 4), 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.

Food Supply

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 (nonprice) 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, 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: $$AC_{tni} = \alpha_{tni} \times (PS_{tni})^{\varepsilon_{iin}} \times \prod_{j \neq i} (PS_{tnj})^{\varepsilon_{ijn}} \times (1 + gA_{tni}) \quad (1)$$

Yield response: $$YC_{tni} = \beta_{tni} \times (PS_{tni})^{\gamma_{iin}} \times \prod_{k} (PF_{tnk})^{\gamma_{ikn}} \times (1 + gCY_{tni}) \quad (2)$$

Production: $$QS_{tni} = AC_{tni} \times YC_{tni} \quad (3)$$

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
	ε	=	area price elasticity
	γ	=	yield price elasticity
	α	=	crop area intercept
	β	=	crop yield intercept

The nonprice yield trend projections are central to projecting yield. The sources of growth considered in these projected trend factors include:

1. Public research (by international and national agricultural research centers)

    a. Management research
    b. Conventional plant breeding
    c. Wide-crossing/hybridization breeding
    d. Biotechnology (transgenic) breeding
2. Private sector agriculturally related research and development
3. Agricultural extension and farmers schooling
4. Markets
5. Infrastructure
6. Irrigation

The growth contribution of modern inputs such as fertilizers is accounted for in price effects in the yield response function and as a complementary input with irrigation and with the modern varieties generated by research. To generate the projected time path of yield growth, the methodology makes use of before-the-fact and after-the-fact studies of agricultural research priority setting, studies of the sources of agricultural productivity growth, an examination of the role of industrialization in growth, and expert opinion (Evenson and Rosegrant, 1995).

Livestock Production.

Livestock production is modeled similarly to crop production except that livestock yield reflects only the effects of expected developments in technology (Equation 5). 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 4). Total production is calculated by multiplying the slaughtered number of animals by the yield per head (Equation 6).

Number slaughtered:

$$AL_{tni} = \alpha_{tni} \times (PS_{tni})^{\varepsilon_{iin}} \times \prod_{j \neq i} (PS_{tnj})^{\varepsilon_{ijn}} \times \prod_{b \neq i} (PI_{tnb})^{\gamma_{ibn}} \times (1 + gSL_{tni}) \quad (4)$$

Yield:
$$YL_{tni} = (1 + gLY_{tni}) \times YL_{t-1,ni} \quad (5)$$

Production:
$$QS_{tni} = AL_{tni} \times YL_{tni} \quad (6)$$

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
α	=	intercept of number of slaughtered livestock
ε	=	price elasticity of number of slaughtered livestock
γ	=	feed price elasticity

The remaining variables are defined as for crop production.

Food Demand

Domestic demand for a commodity is the sum of its demand for food, feed, and other uses (Equation 12). 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 7). Per capita income and population increase annually according to country-specific population and income growth rates as shown in Equations 8 and 9. 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 10). The equation also incorporates a technology parameter

that indicates improvements in feeding efficiencies. The demand for other uses is estimated as a proportion of food and feed demand (Equation 11). Note that total demand for livestock consist only of food demand.

Demand for food:

$$QF_{tni} = \alpha_{tni} \times (PD_{tni})^{\varepsilon_{iin}} \times \prod_{j \neq i} (PD_{tnj})^{\varepsilon_{ijn}} \times (INC_{tn})^{\eta_{in}} \times POP_{tn} \quad (7)$$

where $$INC_{tn} = INC_{t-1,ni} \times (1 + gI_{tn}) \quad (8)$$

and $$POP_{tn} = POP_{t-1,ni} \times (1 + gP_{tn}) \quad (9)$$

Demand for feed:

$$QL_{tnb} = \beta_{tnb} \times \sum_{l} (QS_{tnl} \times FR_{tnbl}) \times (PI_{tnb})^{\gamma_{bn}} \times \prod_{o \neq b} (PI_{tnb})^{\gamma_{bon}} \times (1 + FE_{tnb}) \quad (10)$$

Demand for other uses: $$QE_{tni} = QE_{t-1,ni} \times \frac{(QF_{tni} + QL_{tni})}{(QF_{t-1,ni} + QL_{t-1,ni})} \quad (11)$$

Total demand: $$QD_{tni} = QF_{tni} + QL_{tni} + QE_{tni} \quad (12)$$

where

QD	=	total demand
QF	=	demand for food
QL	=	derived demand for feed
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
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
ε	=	price elasticity of food demand
γ	=	price elasticity of feed demand

η = income elasticity of food demand
α = food demand intercept
β = feed demand intercept
The rest of the variables are as defined above.

The source of supply and demand data is the FAOSTAT database (www.fao.org), UN (1998) was used for the population data, while elasticities and growth rates are obtained from literature reviews and expert estimates.

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)[1], 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 13). Consumer prices are obtained by adding the MI value to the world price and reducing it by the CSE value (Equation 14). 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 15).

Producer prices: $$PS_{tni} = [PW_i \ (1 - MI_{tni})](1 + PSE_{tni}) \quad (13)$$

1 Source: Ingco and Ng (1998); Fan and Tuan (1998); Finger et al. (1996);McDougall et al. (1998); UNCTAD (various years); Valdes (1996); Valdes and Schaeffer(1995a); Valdes and Schaeffer(1995b);

Consumer prices: $$PD_{tni} = [PW_i \ (1 + MI_{tni})](1 - CSE_{tni}) \quad (14)$$

Intermediate (feed) prices: $$PI_{tni} = [PW_i \ (1 + 0.5MI_{tni})](1 - CSE_{tni}) \quad (15)$$

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.

Most prices are obtained from the World Bank's Global Commodity Markets; A Comprehensive Review and Price Forecast (World Bank, 2000)[2]. The ones that were not available in this report were collected from the Food and Agriculture Organization (FAO 2000a, 2000b) and the USDA's National Agricultural Statistics Service (NASS) (USDA, 2000).

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 16). 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: $$QT_{tni} = QS_{tni} - QD_{tni} \quad (16)$$

where
QT = volume of trade
QS = domestic supply of the commodity

Valdes and Schaeffer(1995c); Valdes and Schaeffer(1995d).
2 Although we use a three-year average around 1997 for all other variables in the baseline, it was decided to use a 1998 three-year average for most prices, in order to capture the recent downturn in commodity prices.

QD = domestic demand of the commodity
i = commodity index specific for all commodities
The rest of the variables are as defined earlier.

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 17 , the market-clearing condition.

$$\sum_{n} QT_{tmi} = 0 \tag{17}$$

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 13-15). 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.

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APPENDIX 2: IMPACT COUNTRIES/REGIONS AND COMMODITIES

Countries & Regions

1. USA
2. Europe (EU 15)
3. Japan
4. Australia
5. Other Developed
6. Eastern Europe
7. Central Asia
8. Rest Former USSR
9. Mexico
10. Brazil
11. Argentina
12. Colombia
13. Other Latin America
14. Nigeria
15. Northern Sub-Saharan Africa
16. Central & Western Sub-Saharan Africa
17. Southern Sub-Saharan Africa
18. Eastern Sub-Saharan Africa
19. Egypt
20. Turkey
21. Other West Asia/North Africa
22. India
23. Pakistan
24. Banlgadesh
25. Other South Asia
26. Indonesia
27. Thailand
28. Malaysia
29. Philippines
30. Viet Nam
31. Myanmar
32. Other Southeast Asia
33. China
34. South Korea
35. Other East Asia
36. Rest of the World

Commodities

1. Beef
2. Pork
3. Sheep & Goat
4. Poultry
5. Eggs
6. Dairy Animals
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 Fruits
19. Temperate Fruits
20. Sugar Cane
21. Sugar Beets
22. Sweeteners
23. High Value Fish Aquaculture (HVFA)
24. High Value Fish Capture (HVFC)
25. High Value Other Aquaculture (HVOA)
26. High Value Other Capture (HVOC)
27. High Value Crustaceans Aquaculture (HVCA)
28. High Value Crustaceans Capture (HVCC)
29. Low Value Fish Aquaculture (LVFA)
30. Low Value Fish Capture (LVFC)
31. Fish Meal
32. Fish Oil

APPENDIX 3: DEFINITIONS OF IMPACT COUNTRIES AND REGIONS

Developed Countries and Regions

Western World

1. USA
2. Europe (EU 15): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom
3. Japan
4. Australia
5. Other Developed: Canada, Iceland, Israel, Malta, New Zealand, Norway, South Africa, and Switzerland
6. Eastern Europe: Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovakia, Slovenia, and Yugoslavia

Former Soviet Union (FSU)

7. Central Asia: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
8. Rest Former USSR: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Latvia, Lithuania, Moldova, Russian Federation, and Ukraine

Developing Countries and Regions

Central and Latin American

9. Mexico
10. Brazil
11. Argentina
12. Colombia
13. Other Latin America: Antigua and Barbuda, Bahamas, Barbados, Belize, Bolivia, Chile, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent, Suriname, Trinidad and Tobago, Uruguay and Venezuela

Sub-Saharan African

14. Nigeria
15. Northern Sub-Saharan Africa: Burkina Faso, Chad, Djibouti, Eritrea, Ethiopia, Mali, Mauritania, Niger, Somalia, and Sudan
16. Central & Western Sub-Saharan Africa: Benin, Cameroon, Central African Republic, Comoros Island, Congo Democratic Republic, Congo Republic, Gabon,

Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Sao Tome and Principe, Senegal, Sierra Leone, and Togo

17. Southern Sub-Saharan Africa: Angola, Botswana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Reunion, Swaziland, Zambia, and Zimbabwe
18. Eastern Sub-Saharan Africa: Burundi, Kenya, Rwanda, Tanzania, and Uganda

West Asia and North Africa (WANA)

19. Egypt
20. Turkey
21. Other West Asia/North Africa: Algeria, Cyprus, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Saudi Arabia, Syria, Tunisia, United Arab Emirates, and Yemen

South Asian

22. India
23. Pakistan
24. Banlgadesh
25. Other South Asia: Afghanistan, Maldives, Nepal, and Sri Lanka

Southeast Asian

26. Indonesia
27. Thailand
28. Malaysia
29. Philippines
30. Viet Nam
31. Myanmar
32. Other Southeast Asia: Brunei, Cambodia, and Laos

East Asia

33. China: includes Taiwan and Hong Kong
34. South Korea
35. Other East Asia: Democratic People's Republic of Korea, Macao, and Mongolia

Rest of the world

36. Rest of the World: Cape Verde, Fiji, French Polynesia, Kiribati, New Guinea, Papua New Guinea, Seychelles, and Vanuatu

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. 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).
4. 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).

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.).

Crops

Grains

7. Wheat: (Used mainly for human food).
8. Rice: Rice milled equivalent (White rice milled from locally grown paddy. Includes semi-milled, whole-milled and parboiled rice).
9. Maize: (Used largely for animal feed and commercial starch production).
10. Other coarse grains: barley (Varieties include with husk and without. Used as a livestock feed, for malt and for preparing foods.), millet (Used locally, both as a food and as a livestock feed.), 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.), and sorghum (A cereal that has both food and feed uses.)

Roots and Tubers

11. Potatoes: (Mainly used for human food).
12. 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 or pellets) and yams (A starchy staple foodstuff, normally eaten as a vegetable, boiled, baked or fried).
13. 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).

Other

14. 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.
15. 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, fish meal, meat and blood meal (Residue from oil extraction, mainly used for feed).
16. Oils: vegetable oils and products, animal fats and products (Obtained by pressure or solvent extraction. Used mainly for food).

Vegetables

17. Vegetables: Olives, Onions, Tomatoes, and miscellaneous vegetables.

Fruits

18. Tropical Fruits: Bananas, Cantaloupes & other melons, citrus fruits, dates, grapefruit, lemons, limes, oranges, pineapples, plantains, watermelons, miscellaneous tropical fruits.
19. Temperate Fruits: Apples, grapes and miscellaneous temperate fruits.

Sugar and Sweeteners

20. Sugar Cane
21. Sugar Beets
22. Sweeteners: products used for sweetening that are derived from sugar crops, cereals, fruits or milk, or that are produced by insects. This category includes a wide variety of monosaccharides (glucose and fructose) and disaccharides (sucrose and saccharose). They exist either in a crystallized state as sugar, or in thick liquid form as syrups

Fish

23. High-value Fish (aquaculture): Cods, hakes, haddocks, flounders, halibut, soles, redfishes, basses, confers, salmon, trout, smelts, shanks, rays, chimaeras, sturgeons, paddlefishes, tunas, bonitos, bullfishes.
24. High-value Fish (capture)
25. High-value Other (aquaculture): Abalones, winkles, conchs, clams, cockles, arkshells, freshwater mollusks, mussels, oysters, scallops, pectens, squids, cuttlefishes, octopuses, miscellaneous marine mollusks.
26. High-value Other (capture)
27. High-value Crustaceans (aquaculture): freshwater crustaceans, horseshoe crabs, lobsters, spiny rock lobsters; miscellaneous marine crustaceans; sea-spiders, crabs, shrimp, prawns, squat-lobsters.

28. High-value Crustaceans (capture)
29. Low-value Fish (aquaculture): Carps, barbals and other cyprinids; Herrings, sardines, anchovies, jacks, mullets, sauries, mackerel, snoeks, cutlassfish; tilapias and other cichlids; river eels, shads; miscellaneous freshwater fishes; miscellaneous diadromous fishes; miscellaneous marine fishes[3].
30. Low-value Fish (capture)
31. Fish Meal
32. Fish Oil

Source: FAO (2000a) and Delgado et al. (2003)

3 These classifications follow ISCAAP categorizations. See Delgado et al., 2003

APPENDIX 5: SCHEMATIC PRESENTATION OF IMPACT