DYNAMIC SIMULATION MODEL FOR LONG TERM COMPREHENSIVE ENVIRONMENTAL ANALYSIS OF GAP

by

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This research is intended to be a contribution towards the eventual goal of achieving natural, social and economical sustainability in development process. I dedicate it to the peoples living in GAP region.

ABSTRACT

Integrated development projects based on water resources development, aiming hydropower production and agricultural modernization have many potential impacts on social and natural environments. Southeastern Anatolian Project (GAP), located in Southeast Turkey, comprising 10% of Turkish lands, targeting irrigation schemes on 1.7 million hectare fertile lowlands and 7400 MW hydropower production on Euphrates and Tigris would have many social and environmental consequences.

In this study, potential environmental problems suggested by GAP, questions related with utilization of water resources, land degradation, agricultural pollution and land use are analyzed in systems perspective, focusing on the integrity of environmental, social and economic issues. With this aim, GAPSIM, a dynamic simulation model is developed to trace long term trajectories of selected parameters, representing the relevant aspects of GAP's social, economic and natural environment.

Based on a "systemic" problem definition, GAPSIM simulates the development rate of irrigation schemes, hydropower production with respect to changing irrigation releases, water availability on farmlands, crop selection and production, salinization, erosion, pesticide and fertilizer consumption, rangeland and forest quality, urbanization and population dynamics in GAP during 1990-2030 period, which comprises water facilities construction process.

GAPSIM is validated, first "structurally", according to the validation tests suggested by the literature and then, model "behavior" is calibrated with respect to data available for the period 1990-1998. GAPSIM provides a dynamic simulation platform where several scenarios and policy analyses concerning GAP environment can be executed in order to arrive at an improved understanding of GAP as a socio-environmental system.

Scenario and policy runs on GAPSIM reveal that, increased intensity of the most evapotranspirant crop cotton on GAP fields may cause significant water scarcity, which hinders the development rate of irrigation into new acres and inhibits crop yields by decreased water delivery to individual farms.

ÖZET

Su kaynaklarının geliştirilmesine bağlı olarak hidroelektrik enerji üretimini ve tarımsal modernizasyonu hedefleyen entegre kalkınma projeleri, toplumsal ve doğal çevre üzerinde çok sayıda etkiye neden olmaktadır. Türkiye'nin Güneydoğu'sunda, toplam yüzölçümünün % 10'unu kapsayan, 1.7 milyon hektar verimli arazi üzerinde sulama projelerini ve Fırat ve Dicle üzerinde 7400 MW kurulu güce sahip enerji üretim kapasitesini hedefleyen Güneydoğu Anadolu Projesi (GAP) de çok sayıda toplumsal ve çevresel sonuçlara yol açacaktır.

Bu çalışmada, GAP'ın neden olabileceği potansiyel çevre sorunları, su kaynaklarının kullanımı, toprakların vasıfsızlaşması, tarımsal kirlilik ve arazi kullanımı ile ilgili sorunlar, çevresel, toplumsal ve ekonomik sorunların karşılıklı etkileşimlerini dikkate alan sistemik bir bakış açısıyla analiz edilmiştir. Bu amaçla, GAP'ın toplumsal, ekonomik ve doğal çevresinin belli yönlerini temsil eden değişkenlerin uzun vadeli seyirlerini izleyebilmek için, dinamik bir benzetim modeli, GAPSIM geliştirilmiştir.

GAPSIM, "sistemik" bir problem tanımına bağlı olarak, GAP Bölgesinde, sulama yapılarının inşaasını içeren 1990-2030 yılları arasında, sulama projelerinin gelişme hızını, değişen sulama suyu miktarlarına göre hidroelektrik enerjisi üretimini, çiftliklerde su yeterliliğini, ürün seçimi ve üretim miktarlarını, tuzlanma ve erozyon süreçlerini, pestisit ve kimyasal gübre tüketimini, mera ve orman arazilerinin kalitesini ve kentleşme ve nüfus dinamiklerini canlandırmaktadır.

GAPSIM'in geçerliliği, literatür tarafından önerilen sınama yöntemlerine göre "yapısal" olarak sınanmış, ardından model davranışı, elde edilebildiği oranda 1990-1998 yılları arasındaki verilerle kalibre edilmiştir. GAPSIM, GAP toplumsal-çevresel sistemine dair bilimsel bir kavrayışa ulaşabilmek amacıyla çeşitli senaryo ve strateji analizlerinin yapılabileceği bir dinamik benzetim ortamı sunmaktadır.

GAPSIM ile yapılmış olan senaryo ve strateji deneyleri, en yüksek evapotranspirasyon değerine sahip pamuğun bitki deseni içerisinde aşırı yoğunluk kazanması durumunda ciddi bir su kıtlığı ile karşı karşıya kalınabileceğini, bu durumun sulamaların genişleme hızını yavaşlatacağını ve çiftlik verimlerini düşüreceğini göstermektedir.

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I. INTRODUCTION

Southeastern Anatolian Project (GAP) is an integrated development project consisting of 13 water development schemes which involve 22 dams and 19 hydropower plants on Euphrates and Tigris (Figure. 1.1.). By the end of the project, irrigation of 1.7 million ha lands and a hydropower production capacity of 7400 MW is targeted. This makes 22 % of Turkish national hydropower capacity. If energy production losses because of irrigation water releases are ignored, it is expected that, total energy production will reach 27000 GWh/year [1]. It is also declared that, industrial development, stimulated by increased agricultural production and improved infrastructure will create an urban employment capacity of 1.25 million jobs [2]. Total cost of GAP investments are estimated to be 32 billion US dollars of which about 48% have been realized by the end of 1998. However, while about 60% of hydropower production investments has been completed (4404 MW), only about 10% of irrigation development has been accomplished which makes about 183080 ha [3].

In this study, the geography of the provinces Adıyaman, Batman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa and Şırnak is called as GAP region. This region constitutes about 10 % of Turkish national lands (about 7.5 million ha) and according to 1997 census, about 10 % of Turkish national population (about 6.1 million). While about 4 million of this population live in cities and towns, the other 2 million live in villages and subsettlements. Historical values for fertility (average number of children born to a woman) is about 5, and emigration rate is about 3 %. Therefore, while there exists emigration, population of GAP keeps increasing. Also, recent data imply that there is strong migration from rural to urban GAP. The subsistent farm economies and declining rangelands grazing excite this tendency, but on the other hand, population absorption capacity of urban GAP is very low and urban underemployment rate reaches to about 50%.

Among 7.5 million ha of GAP regional lands, 2.5 million ha are the fertile lowlands and about 65 % of these lands are planned to be irrigated by GAP. According to a rather old classification, rangelands constitute an other 2.5 million ha and forests constitute 1.5 million ha of this quantity [4].

GAP is a semiarid region, average annual rainfall ranging between 835 to 350 mm/year from north to south with significant water deficit in summer seasons. With respect to average annual daylight duration and number of days over +5 C^{o}, climate of the region is very suitable for photosynthetic activity and crop production.

In GAP region, low input, low and medium technology mixed farming systems dominate. About 90 % of the farm units deal with crop production together with animal husbandry. Since subsistence is high, fodder production is low, livestock is fed on poor rangelands, on fallow areas or by crop residues. Winter cereals and pulse production with fallow constitute the major agricultural practice and crop diversity is low.

Modernization of agriculture via irrigation and increasing input quantities offer introduction of new summer crops in farm systems and increasing yields in conventional crops by elimination of water deficit and increasing soil nutritional levels. It is expected that, subsistent farm economies which do not allow capital accumulation will be broken, increased agricultural rawmaterial for industry will stimulate urban growth and infrastructure development and energy production will facilitate this process. According to the GAP Master Plan, as GAP develops, the rainfed fields will be transformed to irrigated farm systems by introduction of irrigation, chemical fertilizers, crop protecting materials, high yield varieties and by machinery and equipment. The increased yield in summer crops basically such as cotton, oil crops (sesame, soya, sunflower), cereals (maize, sorghum), vegetables and fruits will initiate agroindustries such as food, beverages and textile production creating a synergistic urban development.

But, agricultural modernization and accompanying regional development in a rural economy have many potential social and environmental problems that exhibit

complex dynamics. Salinisation of arable lands in semiarid regions due to irrigation, nitrate and phosphate accumulation in freshwater supplies because of chemical fertilizers, toxic effects of synthetic pesticides on biota and soil erosion because of insufficient soil conservation practices especially on irrigated lands are of major environmental concern. Also, dynamics of land transformation, which may lead to misuse of fertile arable lands, rangelands or forests are major problems basically affected by pressures created by population. On the other hand, changing environmental quality, agricultural systems and urban growth affect population dynamics. Worldwide evidence on integrated water development schemes shows that, if we ignore a careful analysis of these potential problems, the development process may lead to unintended environmental and social consequences [5,6].

In this study, GAPSIM, a regional simulation model of GAP is developed to trace selected environmental variables for 40 years. GAPSIM is a dynamic simulation model, which handles the long-term potential environmental problems related with GAP in a feedback perspective. GAPSIM focuses on worldwide generic problems of regional development and agricultural modernization practices that also exist in GAP, where many socio-economic processes intervene and effect the dynamic trajectories in long term.

For example, the agricultural land regimes, intensity of certain crops and rotations within the farm systems increase land degradation and pollution related with agricultural input consumption rates. While degradation of arable lands decrease regional yields and profitability of certain crops, market processes, in turn, stimulate certain land regimes under given agronomic constraints.

Regional availability of water for irrigation, hydropower production and urban and industrial use are affected by cropping intensity and water diversion requirements created by different farm systems and by operational preferences between irrigation development and energy production. Any undesired stimulation of high evapotranspirant crops through market processes may result in regional scarcity of irrigation water supply,

inhibiting irrigation development in new acreage and decreasing regional agricultural production.

The dynamics of land transformation between arable lands, rangelands, forests and urban lands are determined by varying population intensities, subsistence levels and urban growth processes. Changing subsistence levels in rural sites and changing job availability in urban sites determine population dynamics of the region. As the population intensity increases, the pressure on forests, illegal cutting and rate of deforestation for agricultural land use increases. The intensity of grazing on rangelands effects the dynamics of changing rangeland qualities.

While increasing agricultural production stimulates urban growth through industrialization, urban growth encourages agricultural production by creating demand for agricultural commodities. On the other hand, urban growth may set its own limits by determining the land and population constraints.

Therefore, understanding the dynamic interactions of land use, agricultural pollution, migration rates, urban growth and water utilization in a regional development process requires a systemic, holistic conceptualization of the problem and a clear identification of the causal structure. Modeling and analysis of GAP as a "complex system" - a high-order, multiple-loop, nonlinear feedback structure - may help us understand the possible long-term trajectories and effective policy alternatives. Through the analysis of behavior characteristics of complex systems, which are counterintuitive, resistant to policy changes and where often short term responses contradict the long term responses, we can arrive at a better understanding so that we can design systems with improved behavior [7].

Figure 1.1. Southeastern Anatolian Project.

II. PROBLEM BACKGROUND

II.1 Social and Environmental Effects of Big Dams: Global Perspective

The construction of big water schemes and extensive agricultural modernization practices related with water resources development projects raise a strong debate among transnational companies, governments, local communities and environmentalists. On the one side, transnationals and governments emphasize the benefits of damming and agricultural modernization activities on the basis of two arguments. First, we need to utilize our potential energy resources in order to supply the energy that will be demanded by future industrial production and future material quality of living. Secondly, we need to double or even triple our current food production in order to prevent any famine that may occur because of the continuing increase in world population.

In developing countries, modernization of agriculture has been traditionally accepted as a must, which should prelude industrialization in order to enable national economic growth. Accordingly, it would (a) increase food production considerably so as to improve nutritional levels; (b) provide productive work for a rapidly increasing rural population; (c) produce export crops to improve foreign trade; (d) support industrial development [8].

On the other hand, worldwide evidence of social and environmental damage related with damming and water resources development that has been reported since 1950's and current issues about agriculture and environmental degradation constitute a set of arguments supported by ecologists, development planners and sometimes by local communities against the traditional view about agricultural modernization and welfare of rural households [5]. According to this view, dams and agricultural modernization activities based on the development of water resources have serious irreversible effects both on the natural and social environment and these problems can not be overcome by technological or administrative innovation.

While the opposing camp documents a large number of adverse consequences of irrigation development projects, the supporters take them as exceptions caused by lack of information or institutional incapability. The documented adverse consequences can be summarized as follows:

(A) Immediate consequences due to flooding of dam reservoirs: problems of resettlement; loss of archaeological sites; loss of endemic species and fertile land.

(B) Consequences after the flood: loss of fertility downstream due to impoundment; effects on aquatic species; climate change; generation of new epidemics.

(C) Consequences related with agricultural practices: salinization on arable lands, pollution due to excessive use of chemicals; increasing soil erosion rates; effect of cash cropping on food production, nutritional levels and rural emigration.

(D) Problems related with urban development: urban pollution problems; urban growth on agricultural lands; immigration.

II.2. Debate on GAP and Environment: A Ubiquitous Problem

Similar debate about Southeastern Anatolian Project (GAP) has been going on between scholars, officials and some non-governmental organizations in Turkey, since late 1980's. On the one side, a large group of scholars and officials have been supporting GAP by referring to the officially declared objectives:

(A) Economic structure should be developed to improve income level of GAP region and to narrow down the regional income difference between GAP and Turkey.

(B) In rural areas, productivity and job opportunities should be improved.

(C) Population absorption capacities of the cities should be enhanced.

(D) A stage of social stability and sustaining economic development should be achieved [9].

In the GAP Master Plan, potential environmental problems were classified under two main groups. First group of problems were those, which could be handled on the basis of individual projects, such as industrial and municipal wastes, urban air pollution, sedimentation in artificial lakes and river coasts etc. For these set of problems environmental impact assessments were required. The second group of problems were those mainly related with land and water resources, such as soil erosion, salinization and waterlogging, deforestation, overgrazing, water pollution due to fertilizers and pesticides, climate change, biological diversity and epidemics. In the Master Plan, it was admitted that, a holistic approach was required for the management and control of the second group of problems and a continuing monitoring and improvement of institutional framework was proposed [9]. But, still, environment was conceptualized as an issue separate from the development process and it was treated as if it could have been managed without focusing on the entirety of the environmental and socio-economic problems. In fact, second group of issues were the "long-term" problems concerning any integrated agricultural modernization and water resources development project which are hard to manage since many socio-economic variables and constraints intervene these processes.

GAP and related environmental issues have been discussed in several meetings and conferences [6,10,11]. In the meetings, though the participating experts confirmed more or less the same set of potential problems, an isolated approach to selected individual issues and a short term problem focus on environmental policy was dominant. The emphasized problems can be categorized as

(A) Problems during the construction activity: loss of fauna; erosion due to excavation; noise pollution; problems of resettlement and loss of archaeological sites on reservoir lands.

(B) Problems related with agricultural practices: salinization and alkalinization of arable lands; chemical fertilizers and pesticides pollution; soil erosion.

(C) Pollution and land misuse related with industrialization process.

(D) Pollution and land misuse related with urbanization process.

Although the above classification is quite broad, first, possible interactions in between environmental problems within a regional socio-economic structure are ignored, second, no distinction is made among the problems based on their time horizon and third, these problems are not analyzed as an integral part of the development process itself. With such an approach, environmental impact assessments were demanded to be lifesavers but no formal analysis for long term sustainability were made with respect to certain environmental criteria such as changing agricultural input requirements to sustain yields under increasing salinity and erosion rates, increasing pressure on rangelands and forests, changing land regimes and crop patterns under the effect of market and environmental conditions and demographics under urban growth and agricultural land transformation.

In order to arrive at a better understanding of environmental problems acting as an integral part of GAP, a long-term analysis of potential environmental problems focusing on the integrity of the issues related with land and water resources can be useful. With a formal systemic approach, we can arrive at effective policy conclusions, which can yield better performance patterns for selected environmental parameters of the GAP system.

III. PROBLEM STATEMENT

GAP is an integrated development project based on the development of water resources in GAP region, promising transformation of rainfed farm systems and animal husbandry, hydropower production and urbanization creating new job opportunities for the rural community.

By the development of irrigation schemes, rainfed farming on large lowlands of the region will be transformed by introduction of summer crops (fiber crops, oil crops, summer cereals, fodder and vegetables), chemical fertilizers, pesticides, high yield varieties and machinery and equipment. The intensity of certain crops and their rotations in GAP farm systems will be determined under the pressures created by market and environmental processes. While changing irrigation requirements of distinct crops increase salinization and certain crop patterns stimulate soil erosion on arable lands, both reducing the soil fertility, and therefore farm productivity, the increasing consumption of chemical fertilizers and pesticides create burden on farm economies by increasing production costs. On the other hand, regional supply and availability of certain crops in the regional market determine the commodity prices, which in turn affects farm economies by changing income rates. Therefore, changing farm productivity, costs and commodity prices determine the intensity of certain crops and their rotations in GAP farm system while the intensity of these crop rotations affect land degradation processes and soil and water pollution in GAP region.

Throughout the development process, increasing agricultural production and input requirement are the stimulus of industrial development and urbanization creating rawmaterials and market for the emerging industries. But, stimulation of high evapotranspirant crops through market and environmental processes and increasing water diversion requirements decrease the availability of irrigation water which inhibits the development of irrigation in new acreages and therefore the transformation in GAP farm systems. Inhibition of transformation in farm systems because of scarcity of irrigation water affects regional agricultural production, input requirement and hence,

urbanization in GAP. Also, operational preferences between water releases for irrigation and hydropower production may affect this process.

Regional food production determined by the agricultural system and job availability determined by the urbanization process affects demographics of the region. As the job opportunities in urban GAP increase, cities act as population attractors and as the rural households become less subsistent by increasing cash crops and decreasing food production, they tend to emigrate towards urban GAP and cities outside the region. On the other hand, population density in rural GAP is an important factor affecting the dynamics of transformation in land use practices as increasing population intensity stimulates overgrazing in rangelands, ranging and firewood supply in forests and heathlands and tillage in marginal lands, all resulting in increased soil erosion rates.

The aim of this study is to analyze the potential environmental problems related with land and water resources of GAP, focusing on the integrity of land degradation, land misuse and pollution with socio-economic processes in long-term perspective. For this purpose, GAPSIM, a dynamic simulation model for long term comprehensive environmental analysis of GAP is developed. GAPSIM provides a macro analysis of GAP environment where many different geography and economies in GAP are aggregated under system variables, averaging diverse set of parameters existing in the real system.

Because of the aggregation level and long term orientation of the model, GAPSIM is not after unique technological solutions to selected environmental problems, but it helps to understand the processes stimulating environmental degradation and to create initiatives which will yield improved system performance by analysis of the causal structure which is responsible for the undesirable performance characteristics. With this standpoint, GAPSIM integrates problems associated with GAP arable lands, water resources, rangelands, forests, urban sites, market and population in feedback perspective, constituting a high order nonlinear complex system and simulates certain variables about these problem components within the years 1990 - 2030. This time horizon comprises GAP project development and completion periods.

IV. RESEARCH METHODOLOGY

The methodology used in development of GAPSIM is "*system dynamics*" modeling and simulation. System dynamics is a simulation based methodology designed for modeling and analysis of large-scale socio-economic systems. A detailed description of the system dynamics approach was first given in "Principles of Systems" [12]. The methodology is used in many fields including global environmental analysis of world system [13,14,15,16], global and regional sustainable development issues [17,18,19], development planning and policy design [20], environmental management [21], water resources planning and management [22,23] and environmental and ecological modeling [24,25].

The key aspect of *system dynamics* is the utilization of feedback principles in the analysis of social systems. As opposed to *unidirectional causality* among problem variables, *feedback causality* is emphasized. For example, while working out factors affecting urban growth we can identify raw materials availability and land availability as variables affecting industry initiation in an urban area. The unidirectional causal representation of the problem, which dominates traditional policy agendas, is represented in Figure 4.1. The arrows represent the direction and polarity of causal effects among variables. Hence, other things being constant, as more land and as more rawmaterial is available, number of industry structures increase.

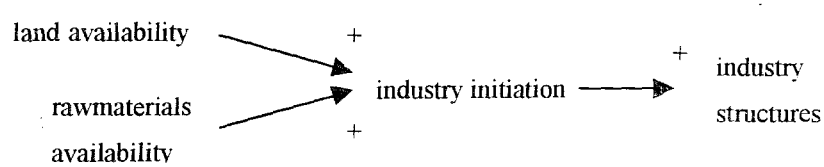


Figure 4.1. Unidirectional causal representation of factors affecting urban growth.

On the other hand, with a feedback conceptualization of the same problem, industry initiation yields more industry structures, which in turn stimulate initiation rate as a result of increased capital availability, etc. (*positive feedback loop*). But industry structures also put limits to its own growth by their land requirement and rawmaterials requirement, decreasing availability of land and rawmaterials, which in turn inhibits industry initiation (*negative feedback loop*). By systems thinking, we arrive at several feedback loops, succession of circular causalities, where the dynamic process leading to urban growth and stagnation is described. The visual representation of the process is Figure is called *causal-loop diagram* (Figure 4.2.).

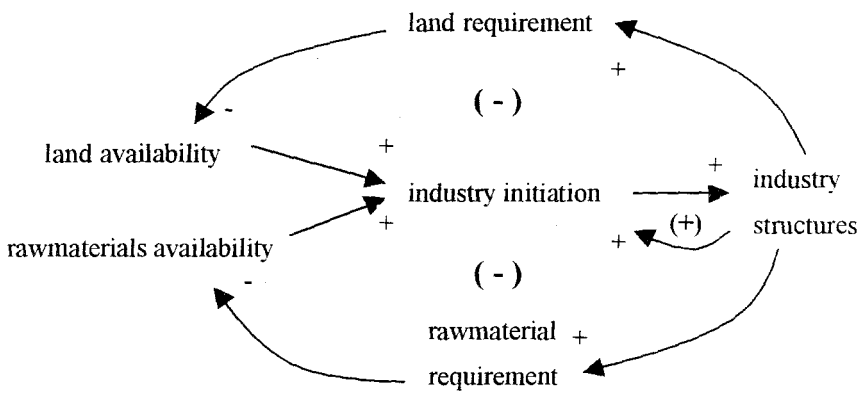


Figure 4.2. Causal loop diagram representing urban growth process.

The nature of causal successions in a feedback loop determines the *polarity* of the loop. *Positive feedback loops* reinforce and thus, over time amplify any initial change and stimulate growth or collapse (*reinforcing loops*). *Negative feedback loops* counteract any initial change (compensating loops) and increase the stability of the systems. Polarity of a loop is found by the algebraic product of the signs of all individual causalities around the loop [26]. By the interaction of two or more feedback loops *complex systems* are constructed (Figure 4.2.).

A systemic feedback model consists of interacting loops forming a complex structure and mathematical equations defining the relationships between the variables of this complex system. Variables in a systemic feedback model are identified as *stock*, *flow* and *converter* variables, where stocks (rectangles) represent accumulating

variables such as industry structures, flows (valves and arrows) represent rates or changes such as industry initiation in the value of stock variables and converters (circles) represent all intermediate variables such as land requirement and rawmaterial requirement. For example, the stock - flow structure for the simple urban growth model is represented in Figure 4.3.

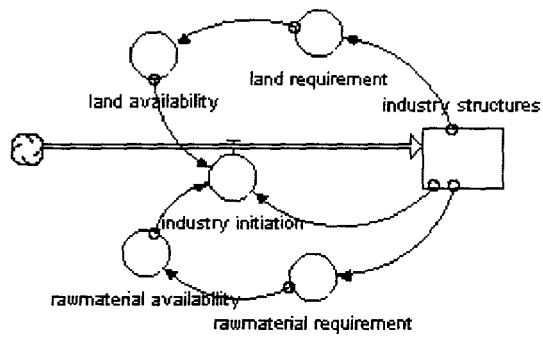


Figure 4.3. Stock - flow structure for the simple urban growth model.

Stock equations are of the general form

$$S(t+dt)=S(t)+dt*(\Sigma flows)$$

Flow and converter equations are specified by the modeler as functions of stocks, other flows and converters.

$$flows=f(stocks, flows, converters)$$ and

$$converters=g(stocks, flows, converters)$$

Stock variables in a systemic feedback model are the state variables of the corresponding mathematical model and behavior of these variables during the simulation constitute performance patterns of the system. For example, the behavior of industry structures as the basic performance measure for the simple urban growth model is illustrated in Figure 4.4.

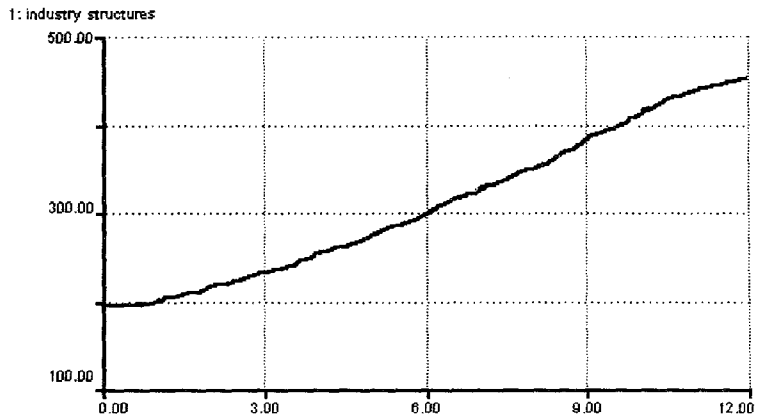


Figure 4.4. Behavior of urban structures in simple urban growth model.

V. MODEL DESCRIPTION

GAPSIM computer model consists of about two thousand variables and fourteen sectors representing different environmental and economic components of the GAP system. In the first section of this chapter, the overview of the model, the sector diagram and major input - output relationships in between the sectors are described. In the second section, a detailed description for each sector including assumptions, variables, causal loop diagrams, stock-flow structures and important formulations are presented. GAPSIM computer model is constructed by STELLA research software [27]. The model is submitted on a separate CD-ROM and its contents is explained in the Appendix.

V.1. Model Overview

In Figure 5.1., GAPSIM sectors and basic interactions are represented. Each block on the diagram represents a sector of GAPSIM. The bold arrows in between box objects represent the land flows, which are the conserved flows in between sectors. Three sectors of the model constituting arable lands in GAP, *rainfed fields*, *irrigated fields* and *wine-garden* are treated as a single object in the Figure for clarity of the presentation but the land flows in between these three sectors are also shown with bold arrows.

Possible land flows in GAPSIM are from rangelands and forestlands to rainfed fields; from rainfed fields to urban lands; from rainfed fields to irrigated fields and in between fields and wine-garden.

V.1.1. Arable Lands

Arable lands in GAPSIM are central to the model, such that, it has interactions with all other sectors except government sector. Three sectors constituting arable lands; *rainfed fields*, *irrigated fields* and *wine-garden* supply agricultural products such as cereals, pulses, cotton, etc. to the *market* and receive information from the *market* about prices of these products. They give information on current crop patterns -hence about input requirements- to *fertilizers*, *pesticides*, *irrigation-salinization* and *erosion sectors* and receive information about fertilizers, pesticides, salinization and erosion effects on yields from these sectors respectively. Arable lands deliver the fodder potential of lands and profitability of non fodder field crops to *livestock and rangelands sector* and receive the population of sheep fed on farmlands from this sector. They receive information of rural population from *population sector* and supply food production to this sector. Finally, arable lands in GAPSIM receive information about irrigation development rate from *water resources sector.*

V.1.2. Livestock and Rangelands

Livestock and rangelands sector supplies agricultural products to the market sector and receives their price information from the market. It receives population density information on arable lands from population sector. It gives range quality information to erosion sector and receives information on erosion effect on rangeland regeneration rates. Finally it receives rangeland costs and rangeland improvement information from *government sector.*

V.1.3. Forests

Forests sector gives forest quality information to erosion sector and receives erosion effect on forests regeneration rates from this sector. It receives timber requirement from *urban sector*. It also receives population density on arable lands and firewood

requirement from population sector. Finally, it receives forest planting information from government sector.

V.1.4. Urban

Urban sector informs market sector about demand for agricultural products. It also delivers water and energy requirements to the water resources sector. This sector receives urban population from population sector and gives information on job availability to this sector. Finally it receives desired public jobs from government sector.

V.1.5. Water Resources

Water resources sector informs arable lands on irrigation development rate. It supplies irrigation water to irrigation and salinization sector and receives farm delivery requirement form this sector. It also receives input about summer crops availability from market sector. Finally it receives irrigation priority and irrigation schemes construction delay information from government sector.

V.1.6. Government

The interactions of government sector with livestock and rangelands, forests, urban and water resources sectors are already decribed. Apart from these, this sector intervenes the market by delivering governmental purchase percentages for individual agricultural product to this sector.

GAPSIM receives external demand for agricultural products (in the market sector), for agricultural processed products (in its urban sector) and for hydropower (in water resources sector). Also, it receives information on exregional job availability (in population sector).

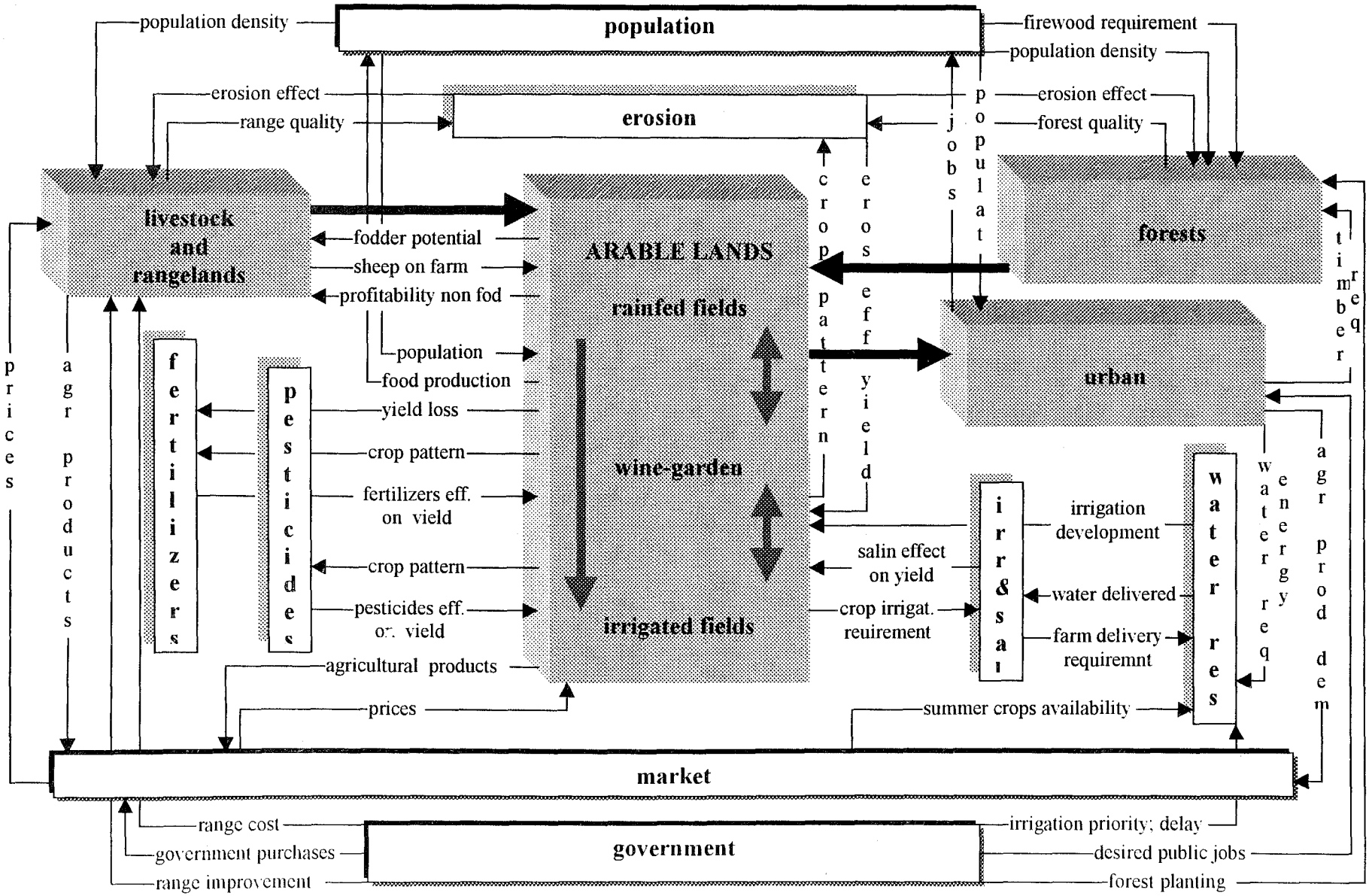


Figure 5.1. GAPSIM Model Overview

V.2. Model Sector Descriptions

V.2.1. Rainfed Fields Sector

Rainfed fields in GAP region adds up to 2.6 million hectares [4]. Currently, the main crops in rainfed fields are cereals (wheat, barley) and pulses (lentil, chickpea). While in the northern part of the region cereals monoculture with fallow is dominant, to the south, crop rotations such as cereals - pulses and very rarely cereals - summer crops emerge [28]. The average percentage occupation of GAP rainfed fields are summarized in Table 5.1. [4]. The cultivation of cereal crops such as rice and corn, legumes such as beans and fodder crops are at negligible levels.

Table 5.1. Percentage of rainfed fields occupied by certain crops in GAP.

cereals % (ha)		**pulses % (ha)**		**fallow % (ha)**
60		20		20
wheat % (ha)	**barley % (ha)**	**lentil % (ha)**	**chickpea % (ha)**	
65	35	85	15	

The regional average yields for these crops are summarized in Table 5.2. [4,29].

Table 5.2. Regional average yields on rainfed fields in GAP.

wheat (kg/ha/year)	**barley(kg/ha/year)**	**lentil (kg/ha/year)**	**chickpea (kg/ha/year)**
1700	1900	1250	1350

The consumption of modern agricultural inputs, basically, high yield varieties, inorganic fertilizers and crop protecting chemicals are very low in current GAP agricultural system. The application rates for several inputs are summarized in Table 5.3. [4,30].

Table 5.3. Regional average agricultural inputs consumption in GAP.

nitrogenous fertilizer (kg/ha/year N)	phosphorus fertilizer (kg/ha/year P_2O_5)	pesticides (lt/ha/year effective material)	seed replenishment quantity (kg/ha/year cereal seeds)
22	12	0.65 - 0.8	15

These values are far below the proposed levels, such as, 60 - 80 kg/ha/year N for cereals and 20 - 30 kg/ha/year N for pulses and 70 - 90 kg/ha/year P_2O_5 for cereals and pulses [31,32], seed replenishment quantities 40 kg/ha/year for cereals and 24 kg/ha/year for pulses [4,33].

Fuel energy consumption in GAP dry farming systems is at medium levels, tillage by tractors and harvesting by combine harvesters are applied in most of the farms but man power is still important since the other stages of farming is not mechanized. Also, level of mechanized farming differs between different farm sizes within the region where large holdings have privileged access to farming machinery.

Most of the farmers in GAP region apply mixed farming system, i.e. they handle both crop and livestock production but since subsistence is high, fodder production is negligible and animals are fed by crop residues and hay or ranged on poor rangelands [4]. Therefore, in GAP rainfed fields, low input and transient technology farming practices dominate resulting in low yields and subsistent rural economy.

V.2.1.1. Rainfed Fields Sector Description.

In GAPSIM rainfed fields sector, it is assumed that, the cultivation of crops other than cereals, pulses and some leguminous fodder crops are at negligible levels and will also be negligible in the future because of the climate constraints on vegetation in dry farming systems. Also, the 65% - 35% share of wheat and barley among cereals and 85% - 15% share of lentil and chickpea among pulses are taken to be constant during yield and input calculations. Hence, GAPSIM rainfed fields sector consists of two stock variables representing two different farm systems in GAP rainfed fields: arable lands allocated for cereals monoculture - CERF and cereals-pulses rotation CEPRF (see Figure 5.2.). In two

crops system, it is assumed that cultivation areas are equally divided. For each field stock a portion of land is allocated for fodder production according to the requirements of livestock imported from livestock and rangelands sector. In calculation of yield, and agricultural input requirement of fodder crops leguminous crops cow vetches and wild vetches are considered. Also, each field stock has an associated fallow percentage taken initially as 20%.

Each rainfed field stock generates its own yields, income, production factors and costs for calculation of profitability associated with that rainfed farm system. These calculations are based on primary farm products such as cereals and pulses and primary production factors such as fertilizers, pesticides, seeds, fuel and labor. During these calculations livestock products and livestock production costs are not included and local consumption of food is dropped. Since each farm system is an aggregation of all rainfed farms applying the same cropping pattern on rainfed fields, associated profits are not exact calculations for individual farms but they represent relative economic advantages of different farm systems.

The transition between different farm systems are modeled through flow variables acting in between two fields and rainfed wine-garden where the rates are adjusted according to three basic criteria: relative profitability of different farm systems; majority effect which creates bias towards dominant farm systems in terms of hectares of land occupied; crop effect which creates bias towards those crops safe in marketing and requiring low know - how. The transition from rainfed fields to irrigated fields are modeled through flow variables representing development of irrigation schemes of GAP, their values are imported from water resources sector. Also, there exists flows from rangelands and forests to rainfed field stocks and from rainfed field stocks to urban land stock. The values of these flows are calculated in relevant sectors (see Figure 5.2.).

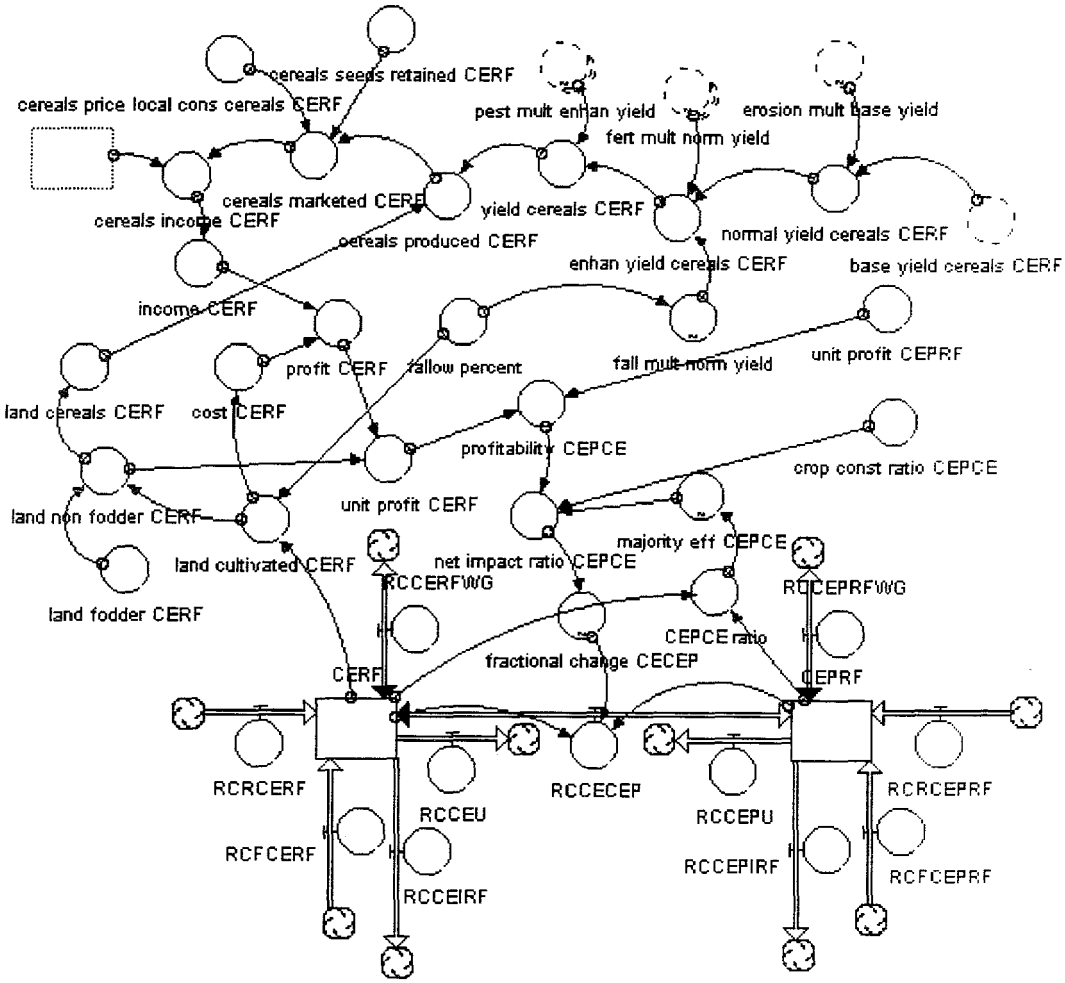


Figure 5.2. Simplified stock flow structure of GAPSIM rainfed fields sector.

Major variables in GAPSIM rainfed fields sector are described below beginning with the stock variables with their units.

CERF: land for cereals monoculture on rainfed fields (ha).

CEPRF: land for cereals pulses rotation on rainfed fields (ha).

Since flow variables associated with CERF and CEPRF are similar, only those related with CERF are given.

RCCECEP: rate of change between CERF and CEPRF (ha/year).

CERFtoRFWG: rate of change between CERF and rainfed wine-garden (ha/year).

CERFtoIR: rate of conversion of CERF to irrigated field (ha/year).

RCCEU: rate of land transfer from CERF to urban lands (ha/year).

RCRCERF: rate of land transfer from rangelands to CERF (ha/year).

RCFCERF: rate of land transfer from forests to CERF (ha/year).

Major converters used in rainfed fields sector are described below.

norm_fallow_percent: initial percentage of fallow on CERF (unitless).

population_eff_fallow_perc: effect o population density on fallow percentages (unitless).

fallow_percent: actual fallow percentage on rainfed fields (unitless).

land_cultivated_CERF: land cultivated on CERF (ha).

land_fodder_CERF: land allocated for fodder production on CERF (ha).

land_non_fodder_CERF: land allocated for non fodder crops production on CERF (ha).

land_cereals_CERF: land allocated for cereals cultivation on CERF (ha).

base_yield_cereals_CERF: cereals yield on CERF under current cultivation techniques (kg/ha/year).

eros_mult_base_yield: variable imported from erosion sector indicating effect of soil erosion on base yield of products (unitless).

normal_yield_cereals_CERF: cereals yield on CERF affected by soil erosion (kg/ha/year).

fall_mult_norm_yield: variable indicating effect of fallow percentage on normal yield of products on CERF (unitless).

fert_mult_norm_yield_CERF: variable imported from fertilizers sector indicating effect of fertilizers consumption on normal yield of products on CERF (unitless).

enhan_yield_cereals_CERF: cereals yield on CERF affected by soil erosion fertilizers use and fallow (kg/ha/year).

yield_loss_CERF: ratio of yield CERF to base yield CERF indicating long term yield loss due to soil erosion, changes in fallow percentages and fertilizer consumption patterns (unitless). In the calculation of this variable, effect of pests are dropped by division, so that, only yield changes due to erosion, fallow and fertilizers are considered.

pest_mult_enhan_yield_CERF: variable imported from pesticides sector indicating effect of pests in relation with pesticides consumption on enhanced yield of products on CERF (unitless).

yield_cereals_CERF: actual cereals yield on CERF calculated finally after effect of pests is incorporated (kg/ha/year).

cereals_produced_CERF: quantity of cereals produced on CERF (kg/year).

cereals_marketed_CERF: quantity of cereals marketed from CERF after local consumption of people and quantity for reproduction is dropped (kg/year).

cereals_income_CERF: income generated on CERF by marketing cereals associated with cereals price in market (TL/year).

income_CERF: total income generated on CERF by marketing primary farm products except livestock products (TL/year).

phosphate_appl_CERF: variable imported from fertilizers sector representing average quantity of phosphorus pesticides applied on CERF in terms of P_2O_5 (kg/ha/year).

nitrogen_appl_CERF: variable imported from fertilizers sector representing average quantity of nitrogenous pesticides applied on CERF in terms of N (kg/ha/year).

pesticides_appl_CERF: variable imported from pesticides sector representing average quantity of pesticides applied on CERF (kg/ha/year).

cereal_seeds_CERF: average quantity of cereal seeds purchased for cereals production on CERF (kg/ha/year).

fuel_CERF: average quantity of fue' consumed on CERF (lt/ha/year).

labor_CERF: peak labor requirement on CERF (man-day/ha).

total_cost_CERF: cost of production of primary farm products with respect to primary input costs on CERF (TL/year).

cost_CERF: cost of production on CERF after livestock cost is dropped from total cost CERF (TL/year).

profit_CERF: average profit generated on CERF with respect to income CERF and cost CERF (TL/ha/year).

profitability_CEPCE: ratio of profit_CEPRF to profit_CERF indicating relative superiority between two farm systems in terms of profit (unitless).

CERF_crop_constant: a constant indicating marketing safety and know - how requirement of crops cultivated on CERF (unitless).

crop_const_ratio_CEPCE: ratio of CEPRF_crop_constant to CERF_crop_constant indicating relative superiority between two farm systems in terms of marketing safety and know - how requirement (unitless).

CEPCE_ratio: ratio of CEPRF to CERF (unitless).

majority_eff_CEPCE: a fraction created by CEPCE_ratio indicating relative superiority between two farm systems in term of their dominance in the fields (unitless).

net_impact_ratio_CEPCE: overall impact on land flow between CERF and CEPRF generated by three factors, profitability_CEPCE; crop_constant_ratio_CEPCE; majority_eff_CEPCE (unitless).

fractional_change_CECEP: the fraction generated by net_impact_ratio_CEPCE which determines the rate of flow in between CERF and CEPRF (fraction/year).

In GAPSIM, since price of farm products are determined endogenously in market sector, several feedback loops act between rainfed fields sector and market sector, each one concerning different field stocks and different farm products. As these feedback mechanisms are similar to each other, one couple of loop concerning one field stock (CERF) and one field product (cereals) is described in Figure 5.3. The variables enclosed with dashed curves are the variables belonging to market sector of the model. As the quantity of lands attributed to cereals monoculture (CERF) increases, land for cereals production increases and this leads to an increase in cereals marketed from CERF. The increasing availability of cereals in regional market implies decreasing cereals prices, therefore decreasing cereals income on CERF and decreasing profitability of CERF compared to CEPRF. This increases the rate of land flow from CERF to CEPRF and results in decreasing CERF constituting the first negative feedback loop. On the other hand, with decreasing CERF, higher ratio of CEPRF to CERF and increased majority effect on rate of transfer from CERF to CEPRF is achieved which further decreases CERF and completes a positive feedback loop.

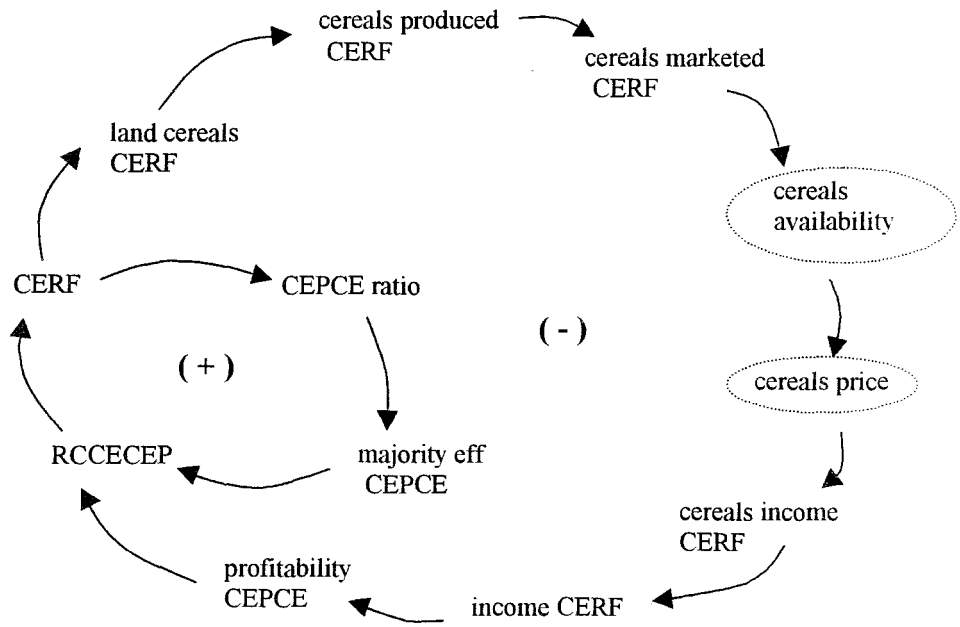


Figure 5.3. Causal loop diagram for GAPSIM rainfed fields sector.

The yield of products on rainfed field stocks are calculated by a couple of multiplications of base yield values with erosion, fallow, fertilizers and pesticides multipliers. For example, cereals yield on CERF (yield_cereals_CERF) is calculated according to the following sequence of operations:

base_yield_cereals_CERF=1650 (kg/ha/year)

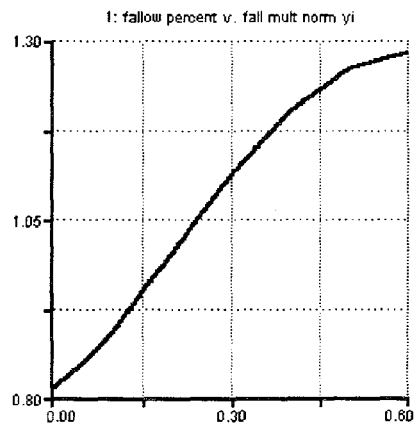
normal_yield_cereals_CERF=_base_yield_cereals_CERF*eros_mult_base_yield (kg/ha/year)

enhan_yield_cereals_CERF=normal_yield_cereals_CERF*fall_mult_norm_yield*fert_mul t_norm_yield_CERF (kg/ha/year)

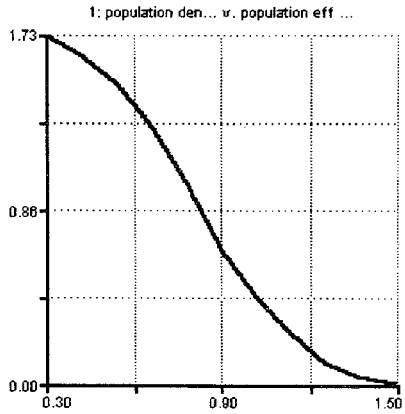
yield_cereals_CERF=enhan_yield_cereals_CERF*pest_mult_enhan_yield_CERF (kg/ha/year)

Data about fallow percentages on GAP rainfed fields are quite contradictory. Some authors support that in GAP agricultural systems on 97% of arable lands fallow practices are applied and as two farm cereals - fallow are cereals - pulses - fallow practices are dominant about half of the rainfed fields are out of production each year [34].

According to a more recent report, 83% of arable lands are cultivated with fallow practices [28]. But, in GAP Master Plan, it is stated that according to 1985 years data land actually on fallow constitutes 10% of all arable lands. In this model, a moderate fallow percentage %20 is taken as normal fallow percentage. Though, we do not have long term experimental data on fallow-yield relationships in GAP region it is sufficiently clear that one year fallow between winter crops in semiarid regions contributes to soil moisture saving about 20% percent of seasonal rainfall and this results in safer yields making significant contribution to long term averages [35]. Summer fallowing represents the single most important practice in wheat production under semiarid conditions [36]. Hence, while modeling effect of fallow percentage on aggregate regional yield of cereals, pulses and fodder crops it is assumed that current fallow percentage will have no effect on normal yield of crops since this value represents yield under normal fallow percentage but increasing fallow will have positive affect and decreasing fallow percentage will have negative effect on aggregate yields according to the following graphical relationship formulating the variable fall_mult_norm_yield:



The change in fallow percentage is hypothesized as a function of population intensity on rainfed fields. As the initial population intensity is exceeded, it forces the population to abandon fallow practices. In the graphical function formulated below, effect of population density on normal fallow percentage is taken to be one for the initial value of population density, which corresponds to 0.8 capita/ha:



Then,

fallow_percent=normal_fallow_percent*population_eff_fallow (unitless)

The formulations for erosion, fertilizer and pest multipliers are discussed in the relevant sectors.

The factors determining farmers' crop preferences and cropping sequences are many and factor of profitability is not the only one. Predicting probable cropping patterns which will be preferred by the farmers is always a major problem in planning and management of farm systems and agricultural economies. According to a research on the crop preferences in Lower Seyhan, it has been found that profitability, know - how and marketing advantages of certain crops and majority of certain crops in the fields had been the basic factors determining the selected crops and farm systems [37]. Hence, farmers tend to cultivate those crops which are profitable, which are safe in marketing, which do not require unusual know-how and which are cultivated by the other farmers in the region.

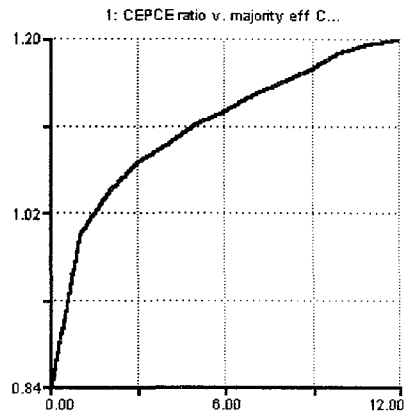
In the formulation of flows in between three field stocks three variables (profitability_CEPCE, crop_const_ratio_CEPCE, CEPCE_ratio) determining transformation of farm systems in rural communities are identified. Below, formulation of flow in between CERF and CEPRF (RCCECEP) is given and this can be generalized for other flows in between field stocks in the model.

profitability_CEPCE=profit_CEPRF/profit_CERF (unitless)

crop_const_ratio_CEPCE=crop_const_CEPF/crop_const_CERF (unitless)

CEPCE_ratio=CEPRF/CERF (unitless)

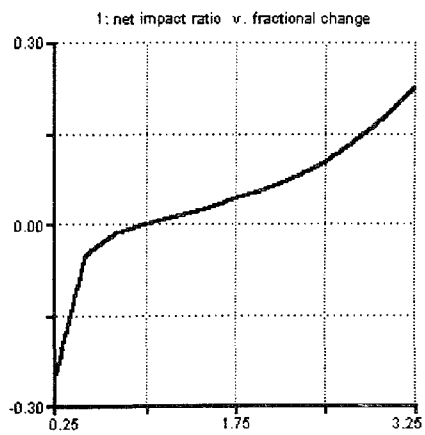
The variable majority_eff_CEPCE creates a bias toward dominant farm system in the fields according to the functional relationship given below:



While calculating net_impact_ratio the impact generated by profitability_CEPCE is modified by the factors crop_const_ratio_CECEP and majority_eff_CECEP.

net_impact_ratio_CEPCE=profitability_CEPCE/crop_const_ratio_CEPCE*majority_eff_CEPCE (unitless)

The variable net_impact_ratio_CEPCE creates fractional_change_CECEP according to the following functional relationship:



Then yearly flow between two field stocks CERF and CEPRF are calculated by the calculation of biflow variable RCCECEP as

RCCECEP=IF(fractional_change_CECEP<=0)THEN(fractional_change_CECEP*CEPRF)ELSE(fractional_change_CECEP*CERF) (ha/year)

Other calculations are given in the description of calculations sector in section V.2.15, where miscellaneous calculations throughout the model are explained.

V.2.2. Irrigated Fields Sector

Irrigated farming in GAP region is very marginal. According to 1988 data about 100.000 ha of arable land is irrigated either by surface or groundwater utilization [9]. In these fields crop diversity is very weak and cotton monoculture is dominant. Production of fodder, oil crops, summer cereals and vegetables are very few in terms of hectares of cultivated lands [28,4]. By GAP irrigation schemes, irrigation on 1.6 million hectares of land is targeted. With this improvement in water availability, farming in GAP will be completely altered by incorporation of new summer crops in farm systems. Main crops feasible under GAP agronomic conditions are fiber crops such as cotton, fodder crops such as alfalfa and vetches, oil crops such as sesame, soya and sunflower, summer cereals such as maize, corn and rice and vegetables [28].

Incorporation of new crops means development of new farm rotations, significant changes in quantity and diversity of agricultural production factors such as water, fertilizers, pesticides, seeds, machinery and labor and modification of the scale of agricultural economies both in terms of income and cost. Though, determination of probable farm systems in the future is difficult, it can be claimed in advance that cotton and cereals as two basic commodities will also be significant in the future and their rotation in a two farm system will be impossible because of the length of time that they occupy on the field [38,39]. Hence, farm systems emphasizing either cotton or cereals will generate, which is quite similar to the current situation. In fields emphasizing cotton production, cotton monoculture or cotton rotation with other summer crops will be possible while in the latter, cereals rotation with some summer crops or more complicated systems comprising cereals, pulses, cotton and other summer crops can be expected. Also, production of second cropping will be possible and some summer cereals, oil crops,

vegetables and fodder crops will be suitable for this purpose [39]. In farms producing fodder crops, scale of animal husbandry will be increased and possibly, the mixed farming character of the region, i.e. crop and livestock production practiced together, will be preserved.

V.2.2.1. Irrigated Fields Sector Description

Irrigated fields in GAPSIM consists of four field stocks representing cotton monoculture (COIF); cotton - summer crop rotation (COSIF); cereals - summer crop rotation (CESIF); cereals - cotton - pulses - summer crops rotation (CCSPIF). The partition of wheat and barley in cereals and partition of lentil and chickpea in pulses are the same with that of rainfed fields. Summer crops in the model consists of oil crops, summer cereals and vegetables. The calculation of yields, prices and input requirements of oil crops are based on values for sesame, soybean and peanut, of summer cereals are based on values for maize, millet and corn, and of vegetables are based on values for beans, peas, head lettuce, spinach, eggplant, tomatoes, melon and watermelon each of them in equal shares.

Also, each field stock has its associated second cropping percentage. For each irrigated field, land generated for second crops is a contribution to the land for summer crops.

In irrigated fields sector each field stock creates its cost and income in the same way as it is in rainfed fields sector and generates land flows in between irrigated field stocks according to the same premises and formulations described in rainfed fields sector. But, while in income calculations of CESIF and CCSPIF local consumption of food is dropped, in COIF and COSIF where winter cereals are not produced, food requirement of the population is added as cost.

Since, stock-flow structure for irrigated fields sector is a more complicated version of rainfed fields sector, it is not given here. Major variables in irrigated fields sector are described below with their units beginning with the stock variables.

COIF: land for cotton monoculture on irrigated fields (ha).

COSIF: land for cotton and summer crops rotation on irrigated fields (ha).

CESIF: land for cereals and summer crops rotation on irrigated fields (ha).

CCSPIF: land for cereals, cotton, pulses and summer crops rotation on irrigated fields (ha).

Since flow variables associated with COIF, COSIF, CESIF and CCSPIF are similar, only those related with COIF are given.

RCCOCOS: rate of change between COIF and COSIF (ha/year).

RCCESCO: rate of change between CESIF and COIF (ha/year).

RCCESCOS: rate of change between CESIF and COSIF (ha/year).

RCCCSPCO: rate of change between CCSPIF and COIF (ha/year).

COIFtoIRWG: rate of change between COIF and irrigated wine-garden (ha/year).

RFtoCOIF: rate of conversion of rainfed field to COIF (ha/year).

Most of the converters used in irrigated fields sector are similar to those in rainfed fields sector. Therefore, here, converter variables particular to irrigated fields are presented.

pot_stay_time_COIF: a variable indicating possible staying time of certain portion of land under farm system COIF (years). This variable is exported to pesticides sector.

norm_land_util_perc_sec: normal percentage of lands utilized for second cropping set as 0.05 (unitless).

sec_crops_avail_eff_sec_crops: effect of second crops availability in market on second cropping percentage (unitless).

land_util_perc_sec: percentage of land utilized for second cropping (unitless).

land_second_COIF: land utilized for second crops on COIF (ha).

base_yield_cotton: cotton yield on irrigated fields under proposed cultivation techniques (kg/ha/year).

sal_mult_cer_fod_cot_base_yield_COIF: variable imported from irrigation and salinisation sector indicating effect of salinisation on base yield of cereals, fodder and cotton products on irrigated fields (unitless).

normal_yield_cotton_COIF: cotton yield on COIF affected by soil erosion and salinisation (kg/ha/year).

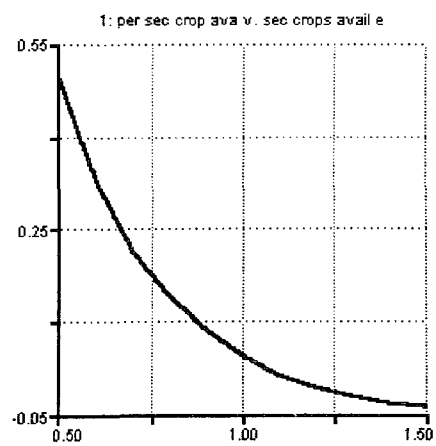
irr_mult_norm_yield_COIF: variable imported from irrigation and salinisation sector indicating effect of irrigation water availability on normal yield of products on COIF (unitless).

enhan_yield_cotton_COIF: cotton yield on COIF affected by soil erosion salinisation irrigation and fertilizers use (kg/ha/year).

yield_cotton_COIF: actual cotton yield on COIF calculated finally after effect of pests is incorporated (kg/ha/year).

The feedback loops acting on the irrigated fields sector is similar to that of rainfed fields. The couple of feedback loop represented in Figure 5.3. acts on four field stocks COIF, COSIF, CESIF and CCSPIF and on 7 commodities produced on irrigated fields cereals, pulses, cotton, oil crops, summer cereals and vegetables in irrigated fields sector.

The effect of summer crops availability on second cropping percentage is formulated by a first order time delay of summer crops availability representing perception delay of the farmers. Functional relationship between perceived second crops availability and sec_crops_avail_eff_sec_crop is formulated as



where

normal_land_util_perc_sec=0.05 (unitless) and

land_util_perc_sec=norm_land_util_perc_sec+sec_crops_avail_eff_sec_crops (unitless)

The calculations for yields in irrigated fields sector is very similar to that in rainfed fields with some modifications. Actual yields are calculated according to the following sequence of operations:

normal_yield_cotton_COIF=base_yield_cotton*eros_mult_base_yield_COIF*sal_mult_base_yield_COIF (kg/ha/year)

enhan_yield_cotton_COIF=normal_yield_cotton_COIF*irr_mult_normal_yield_COIF*fert_mult_norm_yield_COIF (kg/ha/year)

yield_cotton_COIF=enhan_yield_cotton_COIF*pest_mult_enhan_yield_COIF(kg/ha/year)

The functional forms of erosion, salinisation, irrigation, fertilizer and pest multipliers are explained in the relevant sectors.

Land flows in between irrigated field stocks are formulated in the same way as it is in the rainfed fields sector. The functional forms of majority_effect_COSCO and fractional_change_COCOS are same with majority_effect_CEPCE and fractional_change_CEPCE.

While calculating pot_stay_time_COIF, an estimate is made according to the size of the stock variable COIF and its associated flows

pot_stay_time_COIF=COIF/(ABS(RCCCSPCO)+ABS(RCCESCO)+ABS(RCCOCOS)+ABS(RCCOIRWG)+ABS(RCRFFCO)) (years)

Other calculations are given in the description of calculations sector in section V.2.15, together with other miscellaneous calculations of the model.

V.2.3. Wine-Garden Sector

Wine and garden in GAP constitute about 250.000 ha, where grapes and pistachio constitute the majority of fruits on rainfed lands [4]. On these lands, crop diversity is weak and productivity is low. By development of irrigation schemes, it is expected that both diversity and yields in fruit production will be improved. Those fruits that can be produced in GAP agronomic conditions on irrigated garden are basically apple, pear, peach, apricot, etc. together with grapes and pistachio (Meyvecilik Potansiyelinin Geliştirilmesi, GAP Tarımsal Kalkınma Sempozyumu) and appropriate practices for irrigated horticulture is proposed for these products, concerning water, fertilizers, pesticides, sapling, fuel energy and labor requirements [32].

V.2.3.1. Wine-Garden Sector Description

Wine-garden sector in GAPSIM consists of four stock variables representing lands producing grapes pistachio and other fruits such as apple, pear, peach, apricot etc. There exists two stocks acting as material delays between flows from fields to wine-garden, one for flow from rainfed fields to rainfed wine-garden (young_RFWG) and second for flow from irrigated fields to irrigated wine garden (young_IRWG). These two stocks represent young, unproductive wine-garden lands and maturate to productive lands, rainfed wine-garden (RFWG) and irrigated wine-garden (IRWG) in ten years (see Figure 5.4.). In this sector, there also exists a flow from RFWG to IRWG whose value is determined in water resources sector, representing development of irrigation schemes. For each wine-garden stock, yields, income, agricultural input consumption, costs and profits are calculated as it is done in rainfed fields and irrigated fields sectors. The transition between fields and wine garden are modeled according to the same assumptions considered in rainfed fields and irrigated fields sectors, but here an extra land transformation factor is added since switching between fields and wine garden is a radical decision which requires capital and a significant delay in production.

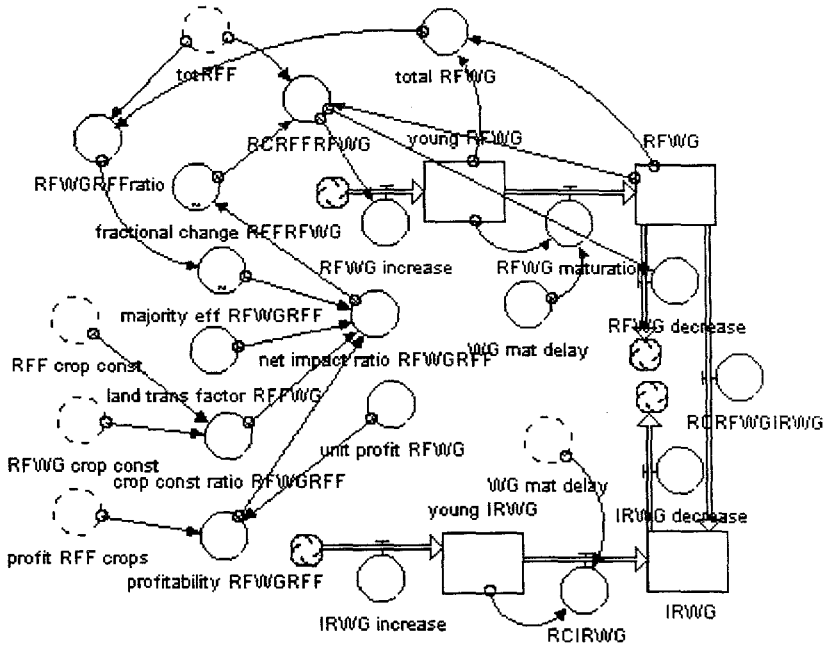


Figure 5.4. Simplified stock-flow structure for GAPSIM wine-garden sector.

Major variables used in GAPSIM wine-garden sector are explained below with their units. Stock variables are

young_RFWG: young, unproductive rainfed wine-garden (ha).

RFWG: rainfed wine garden where fruits are produced (ha).

young_IRWG: young, unproductive irrigated wine-garden (ha).

IRWG: irrigated wine-garden where fruits are produced (ha).

Since flow variables associated with all stock variables are similar, only those related with RFWG and young RFWG are given.

RFWG_increase: increase in young_RFWG due to flow from rainfed fields (ha/year).

RFWG_maturation: increase in RFWG due to maturation of young_RFWG (ha/year).

RFWG_decrease: decrease in RFWG due to flow to rainfed fields (ha/year).

RCRFWGIRWG: rate of change from RFWG to IRWG due to irrigation development (ha/year).

Since converter variables in wine-garden sector are similar to those in rainfed fields and irrigated fields sectors, only those specific to wine-garden sector are described.

WG_mat_delay: average maturation time of young wine-garden to mature (years).

sapling_RFWG: average quantity of sapling purchased for fruits production on RFWG (sapling/ha/year).

land_trans_factor_RFFWG: a constant acting on net impact ratio indicating difficulty of transition from fields to wine-garden because of time delay in production and capital requirement (unitless).

net_impact_ratio_RFWGRFF: overall impact on land flow between RFWG and RFF generated by four factors: profitability_RFWGRFF; crop_constant_ratio_RFWGRF; land_trans_factor_RFFWG; majority_eff_RFWGRFF (unitless).

The feedback loops acting on wine-garden sector is similar to that of rainfed and irrigated fields. The couple of feedback loop represented in Figure 5.3. acts on two wine-garden stocks RFWG and IRWG.

The calculation of yields for RFWG is similar to that for rainfed fields and calculation of yields for IRWG is similar that for irrigated fields. Functional forms for majority_eff_RFWGRFF and fractional_change_RFFRFWG are similar to majority_eff_CEPCE and fractional_change_CECEP in rainfed fields sector.

net_impact_ratio_RFWGRFF=profitability_RFWGRFF/land_trans_factor_RFFWG/crop_const_ratio_RFWGRFF*majority_eff_RFWGRFF (unitless)

Land flows are calculated according to the following sequence of operations:

tot_RFF=CERF+CEPRF (ha)

RCRFFRFWG=IF(fractional_change_RFFRFWG<=0)THEN(RFWG*fractional_change_RFFRFWG) ELSE (tot_RFF*fractional_change_RFFRFWG) (ha/year)

RFWG_increase=IF(RCRFFRFWG>=0)THEN(RCRFFRFWG)ELSE(0) (ha/year)

RFWG_maturation=young_RFWG/WG_mat_delay (ha/year)

RFWG decrease = IF(RCRFFRFWG<=0)THEN(-RCRFFRFWG)ELSE(0) (ha/year)

Other calculations are explained in calculations sector in section V.2.15.

V.2.4. Irrigation and Salinisation Sector

Salinisation is the process that leads to an excessive increase in the salinity of the soil, due to agricultural practices, such that plant growth is prevented. Most salinisation processes (or secondary salinisation as some authors prefer to call, in order to differentiate human induced salinisation from natural process of salt accumulation in arid and semiarid regions where annual evapotranspiration exceeds annual precipitation) result from poor agricultural practices associated with irrigation. Contemporary processes of salt accumulation in irrigated areas are largely determined by the salinity of the water used in an irrigated area and the groundwater balance of that area [40].

As irrigation water is evaporated or transpired, the salts that were in solution are largely left behind and accumulate in the soil. Gradually, these salts will become sufficiently concentrated to preclude plant growth unless surplus water is added to flush the salts out of the soil. However, if this surplus water is not removed from the irrigated lands before it reaches the groundwater, it will result in a rising water table [40]. Irrigation systems are particularly vulnerable when groundwater rises to within 1.5 - 2.5 m of the surface and can be evaporated or transpired causing salts to accumulate [41].

Hence, drainage canals that capture the incremental, salt flushing waters from the irrigated soils prior to reaching the water table, and remove these waters from the area, are as critical in managing a sustainable irrigation scheme as the irrigation canals that deliver the water to the fields and permit plant growth in the first place [42].

Human induced salinisation together with soil erosion is one of the major processes in global land degradation and desertification resulting in reduced productivity of land resources. According to global estimates, about 953 million hectares of land is salt effected and about 10 million ha irrigated land is abandoned every year because of salinisation [43].

Potential problems associated with irrigation and salinisation in GAP are also under discussion. The salinisation problems detected in Lower Seyhan irrigation schemes are reported as potential problems for GAP and efficient drainage systems are proposed [44]. Though, most of GAP arable lands are not actually saline or alkaline, by the development of irrigation schemes, it is probable that, especially in south GAP, salinisation and alkalinisation may become a severe problem [28]. Currently, irrigated fields in Harran plain are subject to high concentrations of soil salinity and rising groundwater levels because of inefficient land drainage systems [45].

V.2.4.1 Irrigation and Salinisation Sector Description

Irrigation and salinisation model in GAPSIM evaluates quantity of irrigation water applied on five irrigated lands (COIF, COSIF, CESIF, CCSPIF, IRWG) with respect to crop irrigation requirements and water availability constraints, portion of this water evapotranspirated which leaves salt on soil root zone and portion infiltrated through root zone which flushes the salt in soil root zone and recharges groundwater. Then, an average salinisation profile for GAP irrigated arable lands is calculated. These calculations are made on annual basis, i.e. any fluctuations in soil salt concentration within the year or problems related with irrigation scheduling throughout the season are ignored. Though models for management of soil water, salinity and yields require spatial data on groundwater hydrology [46], here, basic model assumption is an homogenous evaluative environment where average values of annual precipitation, runoff, groundwater discharge, water table level and initial salt concentrations relevant to GAP apply. Modeling purpose is not to forecast soil salt concentration on any land at any time but to determine valid trajectories for soil salinity with respect to the weight of different farm systems and drainage efficiencies and its effect on yields and profits in arable land sectors.

In this model, precipitation does not contribute to salt accumulation or salt flushing in soil root zone but it acts as a factor in determining the crop irrigation requirements and groundwater balance.

Stock variables in GAPSIM irrigation and salinisation sector are presented below.

salt_conc_root_zone: salt concentration root zone (mg/l), concentration of salts in soil solution at root zone taken initially as 1500. A conversion factor 1 ds/m = 670 mg/l [47] is used for unit conversions from electrical conductivity to concentration.

salt_conc_groundwater: salt concentration groundwater (mg/l), modeled normally as a six years delay of salt_conc_root_zone, taken initially to be 600, in equilibrium with salt_conc_root_zone according to the data for Harran plains [48]. The delay is also adjusted according to the amount of irrigation percolation, so that, when percolation is low, delay is longer.

watertable_level: average watertable depth (mm) applicable for GAP plains, taken initially as -3500.

percieved_water_budget: previous years water budget at root zone perceived by the farmer (mm). This variable acts as a perception delay.

Flow variables associated with these stock variables are as follows.

salt_conc_increase: increase in salt_conc_root_zone calculated according to the quantity of salt released by evapotranspiration (mg/l/year). In this calculation, salt concentration of precipitation and salt removal by crops is ignored. Quantity of salt removed by crops is so small that it will not make a significant contribution to salt removal or enter in determinations of leaching requirements [47].

salt_conc_decrease: decrease in salt_conc_root_zone calculated according to the quantity of irrigation infiltration (mg/l/year). Here, it is assumed that salt concentration of infiltration is equal to salt_conc_root_zone, which is an assumption used in determination of leaching requirements in irrigation practices [49]. In this calculation salts flushed by infiltrating precipitation is ignored since salt releasing effect of precipitation and active salt generation is ignored.

change_groundwater_salt_conc: change in groundwater salt concentration (mg/l/year)

watertable_increase: increase in watertable due to percolation (mm/year)

watertable_subsurf_decrease: decrease in watertable due to subsurface discharge (mm/year). This flow is arbitrarily modeled assuming that, watertable is in equilibrium if there is only precipitation percolation and a certain percentage is discharged if watertable level exceeds a certain threshold.

watertable_surface_decrease: decrease in watertable level due to intrusion to the soil root zone (mm/year). This flow is modeled according to critical watertable level where a certain percentage of groundwater is intruded when this critical level is exceeded.

change_perc_water_budget: change in perceived water budget (mm/year)

Major converters are presented below.

crop_cons_use: crop consumptive-use (evapotranspiration) for each irrigated land stock (mm/year). Calculation is described in arable lands calculations sector in section V.2.15.

eff_precip_percent: effective precipitation percentage is the portion of annual precipitation available for plant consumption (mm/year). Effective precipitation for GAP is taken to for summer crops (April - May - June - July - August - September) about %30 and for winter crops (October - November - December - January - February - March - April - May) about %40 of annual precipitation [50].

crop_irr_requirement: crop irrigation requirement determined according to the difference of crop consumptive-use and effective precipitation (mm/year) [51]. But in this model, not actual effective precipitation but expected effective precipitation is used in calculation of crop irrigation requirement so that farmers precipitation expectation with respect to recent precipitation regime is taken into account. Also, crop_irr_requirement is modified each year according to farmers perception of previous years water budget root zone.

farm_irr_efficiency: farm irrigation efficiency or water application efficiency, ratio of water stored at root zone during irrigation to water delivered to the farm for irrigation (unitless). Excess of delivered water is either runoff or infiltration. For surface irrigation systems, farm irrigation efficiency is generally about %60 but irrigation scheduling and crop choice has effect on this value [49]. Long rooted crops such as cereals and pulses have water storage advantages, they can use irrigation water more beneficially, hence, increase farm irrigation efficiency [35].

farm_delivery_requirement: water required to be delivered to the farm in order to supply necessary water for plant consumption (mm/year). This variable is exported to the water resources sector.

irr_water_applied: irrigation water applied is the minimum of irr_water_delivered (a variable imported from water resources sector) and farm delivery requirement (mm/year).

irr_water_available_root_zone: irrigation water available root zone, calculated by multiplying irr_water_applied with farm_irr_efficiency (mm/year).

irr_runoff_percent: percentage of excess irrigation water directly removed from the field as surface runoff without any significant contribution to flushing of salts in soil root zone (unitless).

irr_infiltration: portion of excess irrigation water infiltrated through soil root zone which flushes salts (mm/year).

drainage_efficiency: a fraction indicating efficiency of land drainage systems which is used in the calculation of the portion of irr_infiltration drained out (unitless).

irr_percolation: portion of irr_infiltration which is not drained out and which recharges groundwater (mm/year).

precipitation: long term average of annual precipitation for GAP region represented by gaussian distribution as NORMAL (500, 120) (mm/year) [50]. This variable is smoothed by a first order time delay of two years in order to prevent unrealistic magnitude in generated precipitation.

basin_recharge_perc: the percentage of annual precipitation water retained by interception, depression storage and soil moisture, the proportion of water that does not contribute to streamflow or groundwater recharge [51]. It is %45 of annual precipitation for GAP on the average [50].

precip_infilt_runoff: portion of annual precipitation which is surplus and recharges streamflow or groundwater (mm/year).

precip_infiltration: portion of precip_infilt_runoff infiltrated through soil root zone (mm/year).

precip_percolation: portion of precip_infiltration which is not drained out and recharges groundwater (mm/year).

runoff: irr_runoff+precip_runoff (mm/year)

infiltration: irr_infiltration+precip_infiltration (mm/year)

percolation : irr_percolation+precip_percolation (mm/year)

drainage: irr_infiltration_drained+precip_infiltration_drained (mm/year)

critical_watertable_level: a threshold value for watertable level where groundwater intrusion begins, taken as 2000 mm below surface [35].

groundwater_intruded_root_zone: annual quantity of groundwater intrusion (mm/year)

water_available_root_zone: water available for plants calculated as summation of irr_water_available_root_zone, effective_precip, groundwater_intruded_root_zone (mm).

water_budget_root_zone: a variable indicating sufficiency of water for crop consumption calculated as the difference between water available root zone and crop consumptive-use (mm).

irr_mult_normal_yield: a variable exported to arable land sectors indicating effect of water budget root zone on crop yields (fraction).

drainage_eff_adj_time_salt_conc_groundw: effect of drainage efficiency, i.e. amount of irrigation percolation on adjustment time of salt_conc_groundwater (unitless)

normal_adj_time_salt_conc_groundw: time delay between salt_conc_groundwater and salt_conc_root_zone when drainage efficiency is zero i.e. all infiltration is percolated (years)

salt_conc_freshwater: salt concentration of water acting as a model constant (mg/l). This variable is set as 600 according to the data provided for Euphrates streamflow.

salt_conc_irr_water: salt concentration of irrigation water modeled as weighted average of salt concentration fresh water, salt concentration root zone and salt concentration groundwater in irrigation water (mg/l).

salt_conc_water_available_root_zone: salt concentration of water evapotranspirated through root zone calculated according to the respective weight of irrigation water and groundwater intrusion (mg/l).

sal_mult_cer_cot_base_yield: variable exported to arable lands sectors indicating effect of salt_conc_root_zone on base yield of cereals and cotton crops (unitless).

sal_mult_oil_sum_cer_base_yield: variable exported to arable lands sectors indicating effect of salt_conc_root_zone on base yield of oil crops and summer cereals (unitless).

sal_mult_puls_veg_fruit_base_yield: variable exported to arable lands sectors indicating effect of salt_conc_root_zone on base yield of pulses, vegetables and fruits (unitless).

In GAPSIM irrigation and salinisation sector two feedback structures act, one controlling the watertable level, hence, groundwater intrusion by adjusting the irrigation water applied according to percieved_water_budget at root zone and the other, reinforcing the salinisation process at root zone through increases at salt concentration groundwater and salt concentration irrigation water (Figure 5.5.). In the causal loop diagram, variables circled with dashed arrows are inputs for arable land sectors and arrows cut with double lines represent information delays.

In the first negative feedback loop, as the quantity of irrigation water applied increases, water available at root zone increases . Surplus in water budget at root zone is controlled by the variable perceived budget at root zone acting as the perception delay of the farmer which decreases the crop irrigation requirement and therefore irrigation water applied. By this process, the first negative feedback which controls excessive consumption of water is completed (see Figure 5.5.). The second negative feedback controls excessive groundwater intrusion by a similar process. As the watertable level increases and as groundwater intrusion at root zone increases, this is controlled by decreasing the irrigation water applied. The third feedback again, controls watertable level. As the watertable level increases, discrepancy with the critical level increases and groundwater intrusion increases. But, increasing groundwater intrusion results in decreasing watertable level.

The positive feedback loops reinforce the salinisation process. As the salt concentration at root zone increases, this creates a long term effect on salt concentration of irrigation water through drainage water and this further increases the salt concentration at root zone through irrigation practice. This completes the first positive feedback. Also, as the salt concentration root zone increases, salt concentration of groundwater, acting as a delay of salt concentration at root zone in the model increases. Salt concentration groundwater increases salt concentration of irrigation water through subsurface discharge. Increasing salt concentration in irrigation water means increasing salt concentration in soil root zone by irrigation practices. This completes the second positive feedback. There exists a third positive feedback created by the effect of salt concentration of groundwater on salt concentration of water available at root zone. This is the process generated by groundwater intrusion.

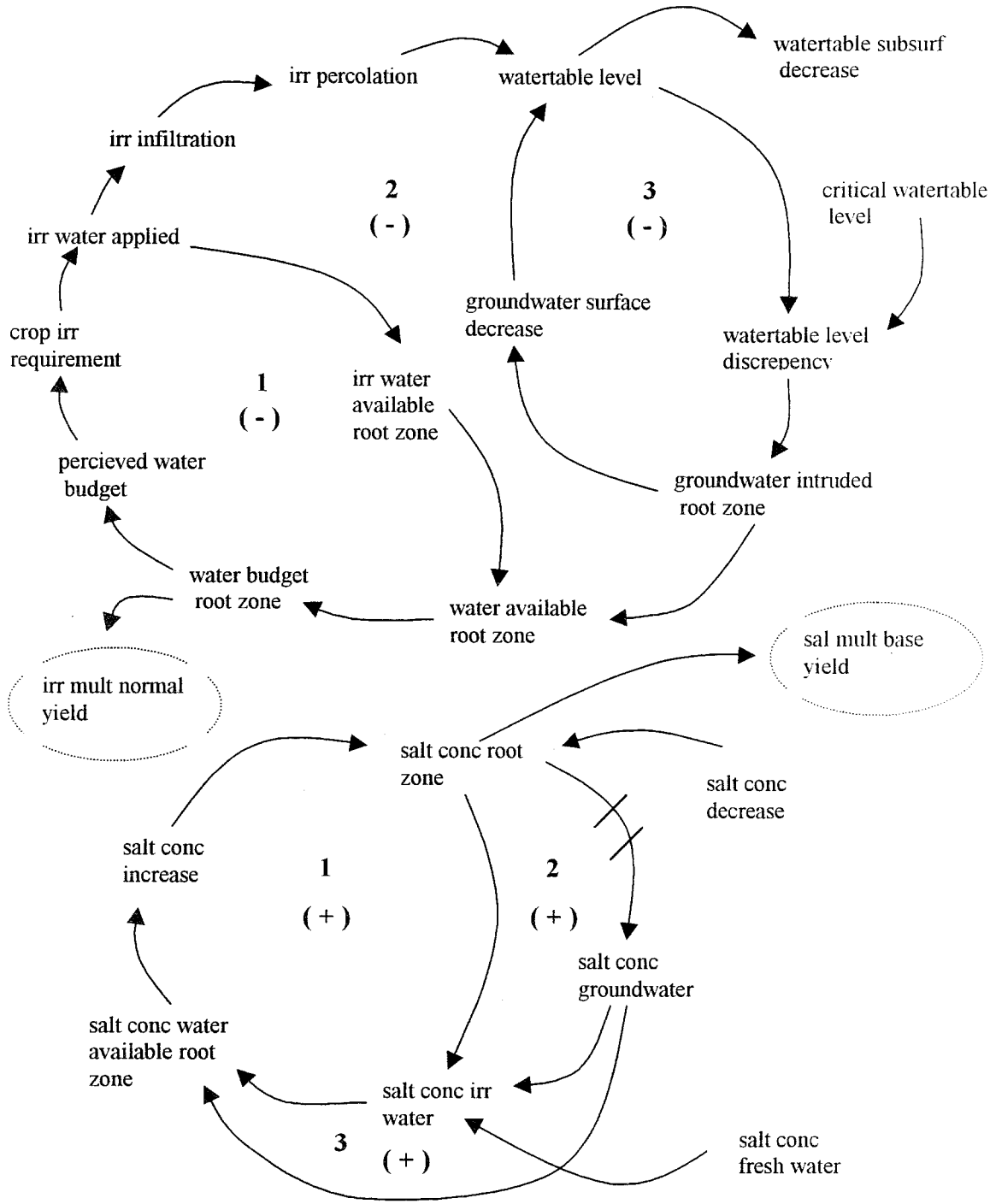


Figure 5.5. Causal loop diagram for irrigation and salinisation sector

The simplified stock - flow structure for irrigation and salinisation sector is presented in Figure 5.6.

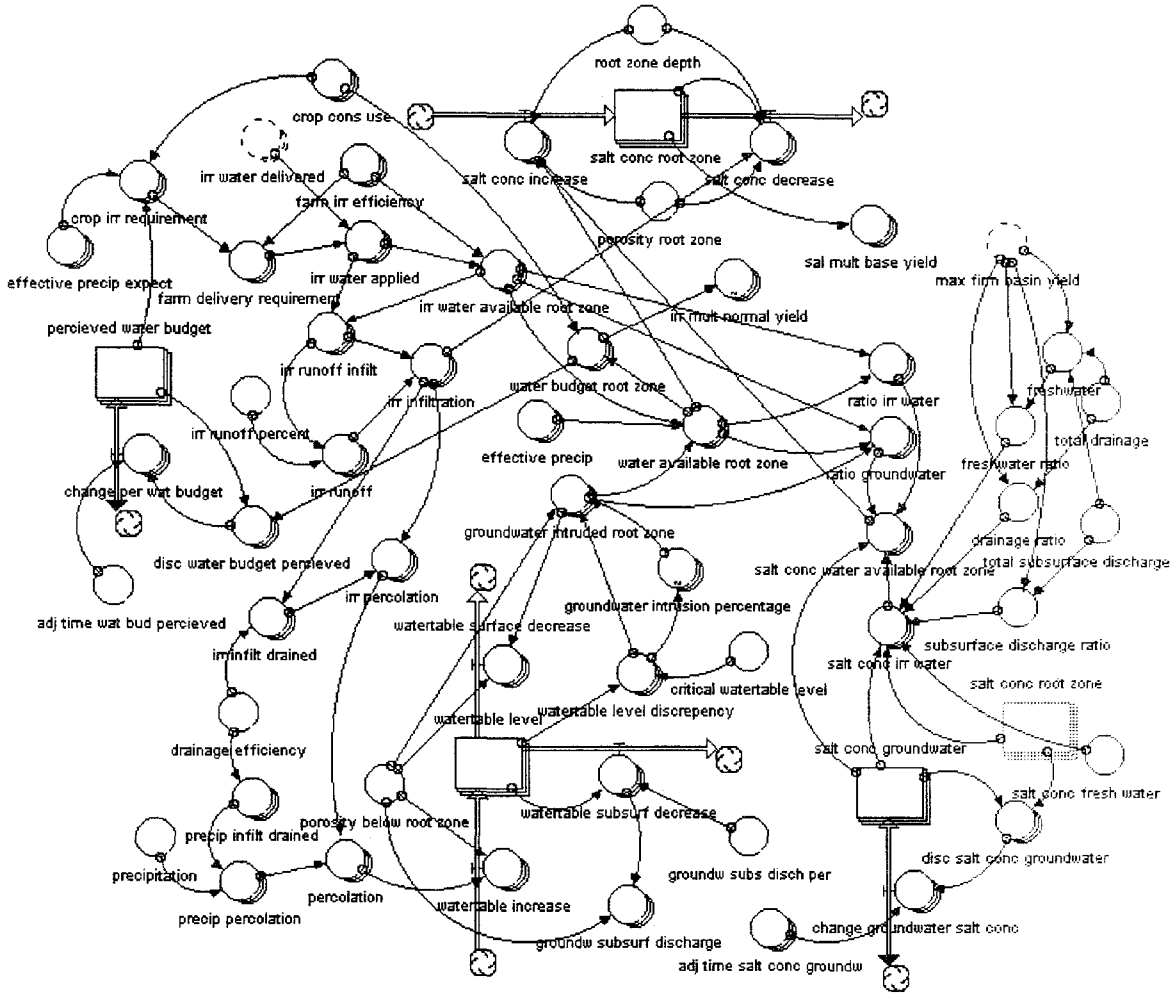


Figure 5.6. Simplified stock - flow structure for irrigation and salinisation sector.

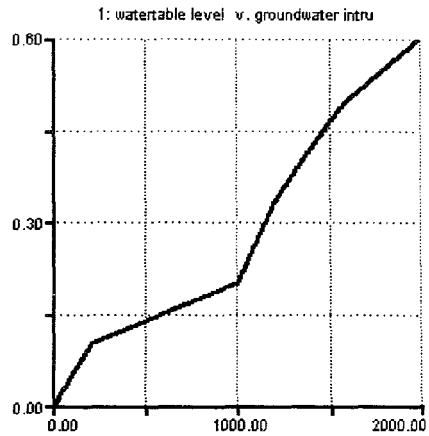
In irrigation and salinisation sector, whenever watertable level exceeds the critical watertable level, groundwater intrusion begins due to capillary forces acting between soil particles and water [35]. In order to calculate this quantity, a table function groundwater_intrusion_percentage is used.

critical_watertable_level=-2000 (mm).

watertable_level_discrepency=watertable_level-critical_watertable_level (mm).

In the formulation of groundwater_intrusion_percentage it is assumed that, when the critical level is exceeded, increasing percentages of groundwater is intruded to the root zone. The root zone is accepted to be the first 1000 mm below soil surface and the intrusion percentage is accepted to begin with 10 % at first 200 mm just above critical level

and increase by 5% for each 200 mm up to the root zone. Groundwater above root zone is accepted to be fully intruded. Then, cumulative averages of these assumed percentages are calculated as groundwater intrusion percentages associated with different watertable levels constituting groundwater_intrusion_percentage as a function of watertable_level_disc:



Then,

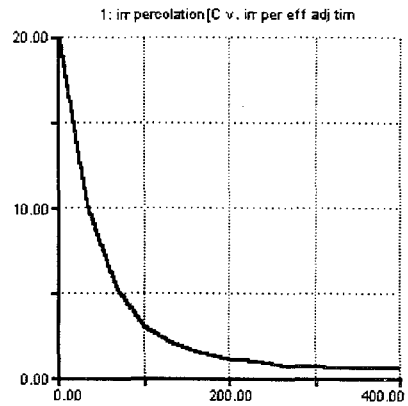
groundwater_intruded_root_zone=watertable_level_discrepency*groundwater_intrusion_percentage*porosity_below_root_zone (mm/year).

Since groundwater is recharged by infiltration with soil root zone salinity, it is assumed that groundwater salinity would be a first order delay of root zone salinity with a certain adjustment time. But for different percolation rates this delay will change. Hence, for irr_percolation under sufficient irrigation, normal_adj_time_salt_conc_groundw is applied and this value is modified with respect to different percolation values according to the following formulation.

normal_adj_time_salt_conc_groundw=6 (years)

irr_per_eff_adj_time_salt_conc_groundw=f(irrigation_percolation) (unitless)

The graphical function for irr_per_eff_adj_time_salt_conc_groudw is presented below:



adj_time_salt_conc_groundw=normal_adj_time_salt_conc_groundw*irr_per_eff_adj_time _salt_conc_groundw (years)

Salt concentration of irrigation water is also subject to change due to irrigation drainage and subsurface discharge of groundwater into freshwater supplies. For this calculation, relative weights of irrigation drainage, groundwater subsurface discharge and freshwater in maximum_firm_basin_yield and their respective salt concentrations are considered. Maximum firm basin yield is a model constant representing maximum quantity of water supplied from Euphrates and Tigris from their lowest rezervuars therefore considers evaporation losses as well (m3/year).

salt_conc_irr_water=salt_conc_groundwater*subsurface_discharge_ratio+salt_conc_root_ zone*drainage_ratio+salt_conc_fresh_water*freshwater_ratio (mg/l)

For example

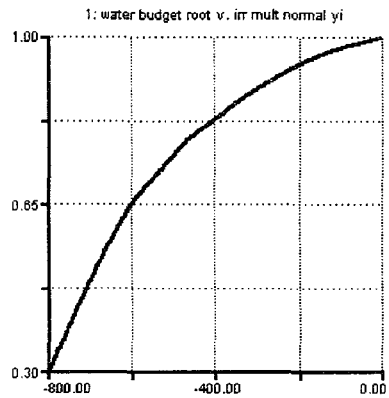
drainage_ratio= total_drainage/max_firm_basin_yield (unitless) and

total_drainage=irrigated_lands*irr_infilt_drained*10 (m3/year)

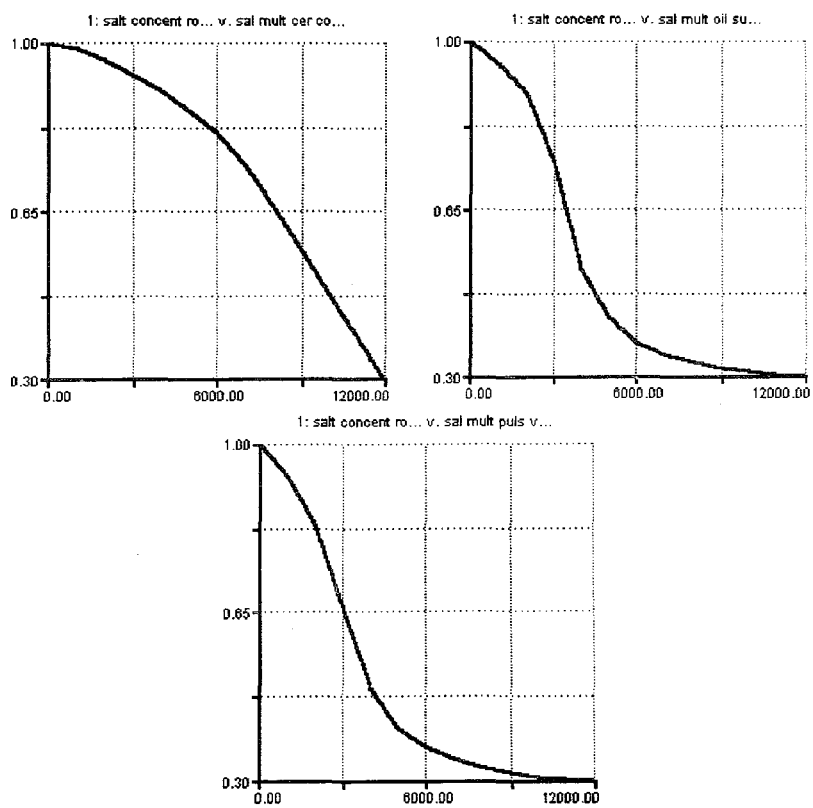
where 10 stands for the conversion factor.

Irrigation and salinisation model has two outputs significant for the yields calculated in arable land sectors. One is irr_mullt_normal_yield, which is a function of water_budget_root_zone and calculates the effect of water availability on yields for five

irrigated land stocks COIF, COSIF, CESIF, CCSPIF and IRWG according to the general growth-moisture content relationship [49]:



Other one is the salinisation multipliers generated for each irrigated land stock for three different crop groups according to the tabulated salt concentration yield relationships [35,47]. According to the available data, crops in GAP region are grouped into three with respect to their salt tolerance: cereals and cotton; oil crops and summer cereals; pulses, vegetables and fruits. Functional form of salinisation multipliers for each group is given below:



V.2.4.2. Irrigation and Salinisation Sector Simulation Runs

Sector isolated run for irrigation and salinisation sector is given in Figure 5.7. In this run there is not a severe increase in salt concentration root zone (mg/l) since the first positive feedback loop in Figure 5.5. is weak, i.e., as total irrigated lands are constant, quantity of drainage water with respect to basin yield is small and salinity of irrigation water supplies (salt_concent_irr_water in mg/l) exhibits a mild increase. Also, salt_concent_groundwater (mg/l) acts as a delay of salt_concent_root_zone. Watertable level (mm) is kept 1250 mm below the soil surface.

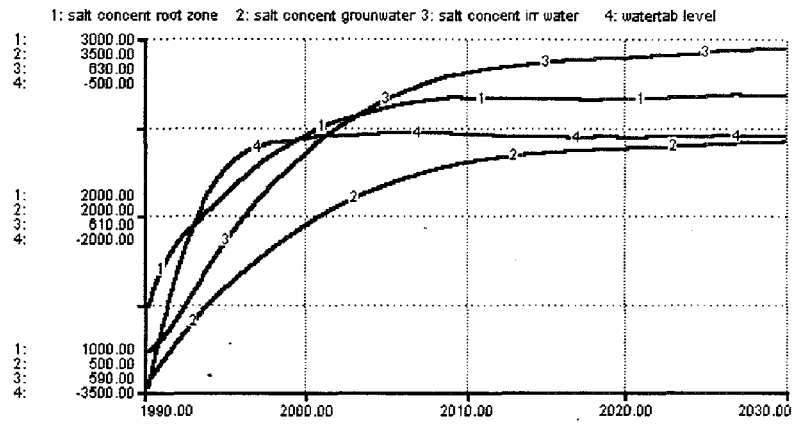


Figure 5.7. Sector isolated run for salinisation and irrigation sector.

But, as the rainfed lands are transformed to irrigated lands as it is targeted by GAP water resources development, quantity of drainage water carrying root zone salinity increases and activates the first positive feedback loop in Figure 5.5., yielding high salt concentration in soil root zone (Figure 5.8.).

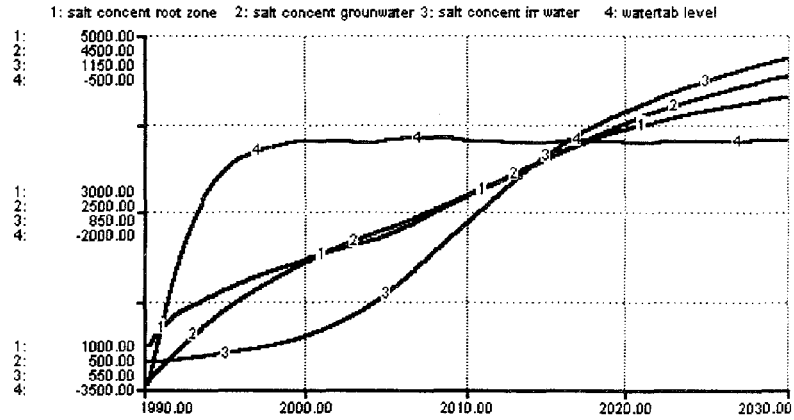


Figure 5.8. Arable lands, water resources and irrigation-salinisation simulation run.

In Figure 5.9., two salinisation control strategies are simulated. In the first run (a), drainage efficiency is increased, i.e., 80% percent of irrigation infiltration is drained out. This is the strategy which weakens second and third positive feedback in Figure 5.5. In the second run (b) in Figure 5.9., a more radical strategy is simulated. Irrigation infiltration is drained out with 80% efficiency and the intrusion of saline drainage water into irrigation water supplies are avoided. Therefore in the second run, all positive feedbacks are weakened.

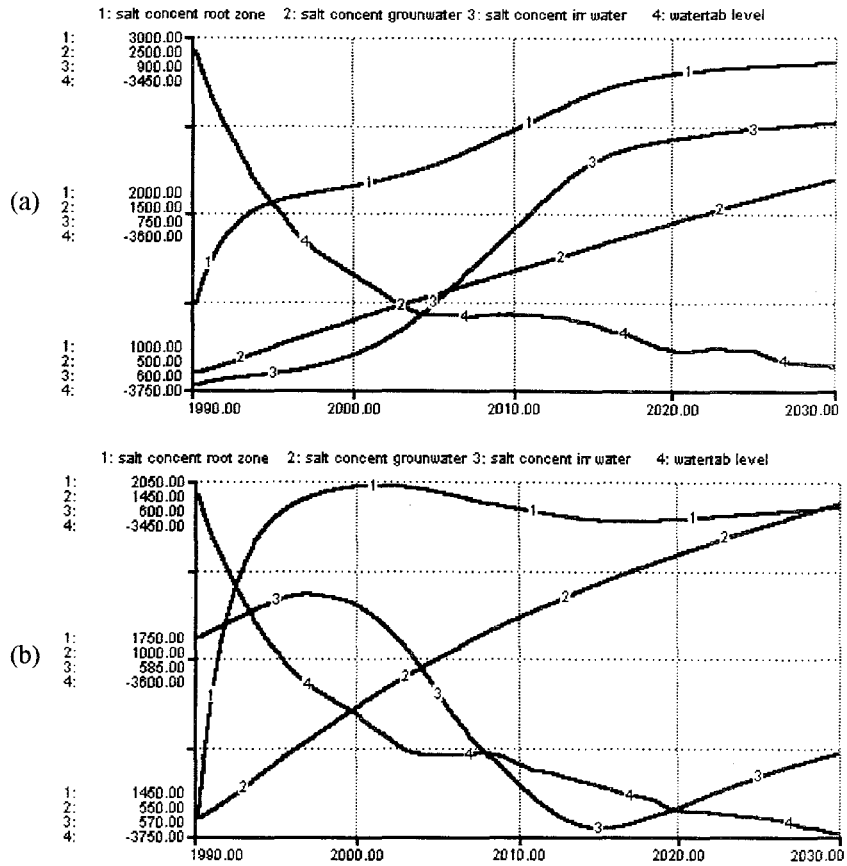


Figure 5.9. Simulation of salinisation control strategies.

In both runs in Figure 5.9, groundwater table is kept below -2000 mm, so that intrusion is avoided and in the second run, root zone salinity is kept at about 2000 mg/l which can be considered as an acceptable level when effects on yields are considered.

V.2.5. Water Resources Sector

By the accomplishment of GAP water resources development projects, 27000 GWh/year firm hydroelectric energy production is targeted. According to macro estimates about GAP water resources and targeted irrigation schemes, at the end of the development, by the irrigation of 1.7 million ha lands, firm hydroelectric energy production will be reduced to about 22000 GWh/year [50]. However, these estimates are based on certain amount of annual water diversion rates for irrigation and are subject to change with respect

to different water requirements and operational preferences during the phase of development.

GAP water resources development consists of 13 projects, 7 on Euphrates and 6 on Tigris basin. These projects are summarized in Table 5.4. [1,50].

Table 5.4. GAP water resources development, targeted irrigation and energy production.

projects	power capacity (MW)	total energy (GWh/year)	irrigation (ha)
Karakaya	1800	7354	
Aşağı Fırat	2450	9024	706281
Sınır Fırat	852	3168	
Suruç - Baziki			146500
Adıyaman - Kahta	195	509	77824
Adıyaman - Göksu - Araban	7	43	71598
Gaziantep			89000
Dicle - Kralkızı	204	444	126080
Batman	198	483	37744
Batman - Silvan	240	964	257000
Garzan	90	315	60000
Ilısu	1200	3833	
Cizre	240	1208	121000
total	**7476**	**27345**	**1693027**

Though, construction of about 22 dams is targeted, 5 dams on Euphrates and 8 dams on Tigris constitute the major source of hydroelectric power and their production will be affected by irrigation releases (Table 5.5.). Other structures are secondary with respect to their contribution on regional hydropower yield.

Table 5.5 Major hydropower plants, their capacity and total hydropower production [1].

project	hydropower plant	power capacity (MW)	total energy (GWh/year)
Karakaya	Karakaya HPP	1800	7354
Aşağı Fırat	Atatürk HPP	2400	8900
Sınır Fırat	Birecik HPP	672	2516
Sınır Fırat	Karkamış HPP	180	652
Adıyaman - Kahta	Kahta HPP	75	171
Dicle Kralkızı	Kralkızı HPP	94	146
Dicle - Kralkızı	Dicle HPP	110	298
Batman	Batman HPP	198	483
Batman - Silvan	Silvan HPP	150	623
Batman - Silvan	Kayseri HPP	90	341
Garzan	Garzan HPP	90	315
Ilısu	Ilısu HPP	1200	3830
Cizre	Cizre HPP	240	1208
total		**7299**	**26683**

Among the dams and hydropower plants, by 1990 only Karakaya was constructed and by 1995, Atatürk was put into operation. By 1995, first stage of Harran irrigation (Aşağı Fırat Project) has begun but, yet, a reliable schedule about development rate of GAP water structures is not available.

V.2.5.1. Water Resources Sector Description

GAPSIM water resources sector evaluates aggregate water releases for hydropower production under different construction and operational constraints with respect to irrigation water requirements generated by arable land sectors. But, macro availability of irrigation water affects actual development rate of irrigation in hectares. Also, high summer crops availability in market sector, indicating low prices for summer crops inhibits actual development of irrigation. Therefore, unless good marketing conditions are generated, the development rate for irrigated lands slows down. GAPSIM water resources sector evaluates rate of transition from rainfed farmlands to irrigated farmlands under water availability and summer crops availability constraints.

Since there is not any reliable schedule available about projected development rate of GAP water structures, a scenario based on 20 years of development beginning in 1995 is considered in the base run. This scenario assumes that GAP water development projects will be accomplished by 2015 and targeted maximum firm hydropower production capacity, targeted maximum irrigation release capacity and targeted irrigation development in terms of hectares will be constructed.

In this sector, all water releases for irrigation and hydropower production from dams on Euphrates and Tigris are aggregated under single variables. GAPSIM water resources sector variables are presented, beginning with the stock variables (Figure 5.11.).

max_firm_energy_production: firm energy production of GAP hydropower plants without any irrigation and urban releases (KWh/year).

existing_irr_release_cap: irrigation release capacity of GAP irrigation schemes (m^3/year).

potential_irrigated_lands: lands ready for irrigation but not irrigated yet (ha).

irrigated_lands: lands actually irrigated (ha).

Flow variables associated with these stock variables are

firm_energy_dev: firm energy production development rate (kWh/$year^2$).

del_irr_rel_cap_dev: delayed irrigation release capacity development (m^3/$year^2$).

de_irr_dev: delayed irrigation development (ha/year).

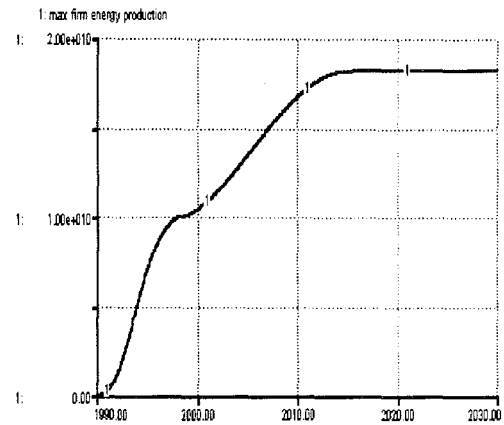
irrigation_development: actual irrigation development (ha/year). This variable represents rate of transformation of rainfed fields and wine-garden to irrigated fields and wine-garden.

Major converters in water resources sector are

max_firm_basin_yield: maximum quantity of water supplied from Euphrates and Tigris from their lowest reservoirs Karkamış and Cizre which is dependable at all times (m3/year). This variable is set as 35 billion m3/year [50].

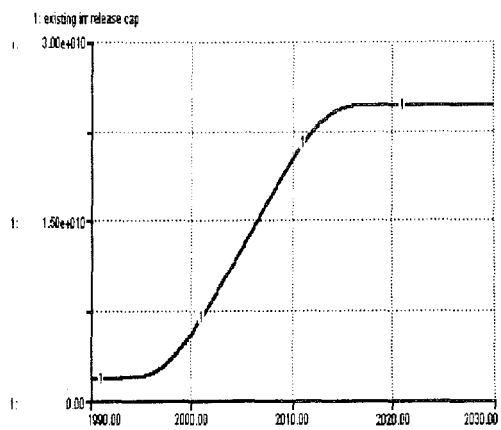
targeted_firm_energy_dev: firm energy production development rate targeted by GAP hydropower plants construction (kWh/$year^2$). This variable excludes Karakaya hydropower

plant which is already constructed in 1990 and is not affected by irrigation releases. This variable is set as a function of time such that, its integral leads to a targeted maximum firm energy production (kWh/year) based on 25 years of development beginning in 1990 and reaching 18.5 billion kWh/year firm energy production by 2015 [1]:



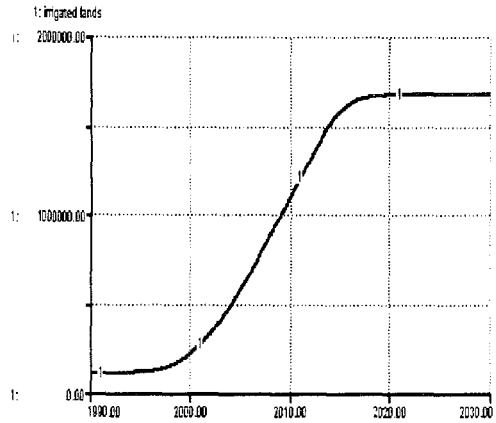
GAP_const_coeff: GAP construction coefficient (unitless), representing modifications in targeted GAP constructions within the simulation period. This constant is set as one in the base run.

targeted_irr_rel_cap_dev: irrigation release capacity development rate targeted by GAP ($m^3/year^2$). This variable is set as a function of time such that, its integral leads to an existing irrigation release capacity ($m^3/year$) based on 20 years of development beginning in 1995 and reaching irrigation release capacity in 2015. According to the design values in "GAP Water Resources", 15 million m3/year water will be diverted for irrigation by the end of the project [50]. Irrigation release capacity is set as 3/2 of this design value:



modified_irr_rel_cap_dev: targeted_irr_rel_cap_dev modified by GAP_const_coeff ($m^3/year^2$).

targeted_irr_dev: targeted irrigation development rate targeted by GAP irrigation schemes (ha/year). This variable is set as a time function where irrigated lands accumulate to 1.7 million hectares by development in between 1995 and 2015 [1]:



modified_irr_dev: targeted_irr_dev modified by GAP_const_coeff (ha/year).

irr_schemes_const_delay: time factor representing delay in irrigation schemes development (years).

irr_priority_in_operation: a constant between 1 and 2 indicating priority of irrigation to hydropower production, 1 representing the highest priority for irrigation, i.e., all the demand is tried to be satisfied if it does not exceed capacity (unitless). This variable is gradually increased to 1.5 in the base run in order to avoid unacceptably low hydropower production.

utilised_irr_relese_cap: the portion of existing irrigation release capacity allowed to be used according to the priority indicated by irr_priority_in_operation (m^3/year).

water_conveyance_eff: water conveyance efficiency is a fraction associated with the losses in the phase of delivery of water to the farmlands due to seepage and evaporation in open channels (unitless).

water_diversion_requirement: the quantity of water that must be diverted to farmlands in order to satisfy farm delivery requirement (m^3/year). This variable is calculated by farm_delivery_requirement imported from irrigation and salinisation sector.

irrigation_release: actual release for irrigation calculated as MIN(utilised_irr_release_cap,water_diversion_requirement) (m^3/year).

irrigation_water_avail: a variable indicating availability water for irrigation at macro level measured as a ratio of utilised_irr_release_cap to water_diversion_requirement (unitless).

irr_water_avail_eff_irr_dev: effect of irrigation_water_avail on development rate of irrigated lands, implying farmers willingness to transform their lands (unitless).

sum_crops_avail_eff_irr_dev: effect of summer crops availability in market on development of irrigated lands (unitless).

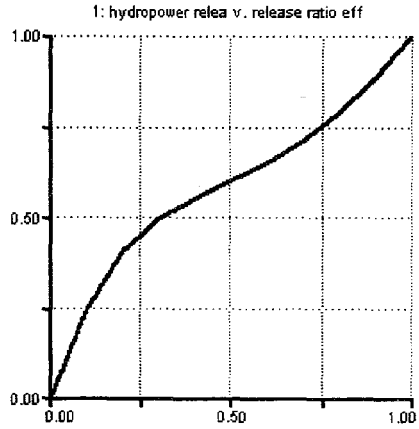
irr_water_delivered: irrigation water delivered to farmlands, a variable exported to irrigation and salinisation sector (mm/year).

urban_water_req: industrial and domestic water requirement calculated in urban sector (m^3/year).

hydropower_gen_release: portion of firm basin yield utilized for hydropower generation and instream flow after releases for irrigation and urban requirements are dropped (m^3/year).

hydropower_release_ratio: ratio of hydropower_gen_release to max_firm_basin_yield (unitless).

release_ratio_eff_energy_prod: effect of hydropower release ratio on firm_energy_production (unitless). This functional relationship is summarized from "GAP Water Resources", where trade off between firm energy production and irrigation releases are tabulated. Superposition of Euphrates and Tigris data leads to a relationship where 50% hydropower_release_ratio results in 40% decrease in energy production [50]. The rest of the functional relationship is arbitrarily completed according to the fact that 0 m3/year hydropower release results in 0 KWh/year energy production:



karakaya_firm_energy: firm energy production of Karakaya hydropower plant which is not affected by irrigation releases (kWh/year). Set as 6.5 billion kWh/year [1].

firm_energy_production: firm energy production calculated according to the formulation karakaya_firm_energy+max_firm_energy_production*release_ratio_eff_energy_prod (kWh/year)

regional_energy_requirement: regional energy requirement calculated as summation of urban and irrigation energy requirements divided by energy transfer efficiency (kWh/year).

exregional_available_energy: energy available for exregional consumption, calculated by the subtraction of regional energy requirement from firm energy production (kWh/year).

In GAPSIM two negative feedback loops control development rate of irrigation in hectares (Figure 5.10.). As water diversion requirement increases, irrigation water availability decreases and reduces the irrigation development rate. Reduced irrigation development rate results in reduced total irrigated lands and water diversion requirement decreases. This constitutes the first negative feedback controlling the regional irrigation development in hectares. Second negative feedback controlling the irrigation development rate is related with marketing constraints. As total irrigated lands increase, regional production and marketing of summer crops increase. But, increasing summer crops availability indicates marketing difficulties and low prices. Under these conditions, farmers willingness to transform their lands from rainfed practices to irrigation falls down. This has an aggregate negative effect on development rate of irrigation in hectares. This results in decreased total irrigated lands constituting the second negative feedback loop. In Figure

5.10., The variables enclosed with dashed circles belong to irrigation and salinisation and market sectors.

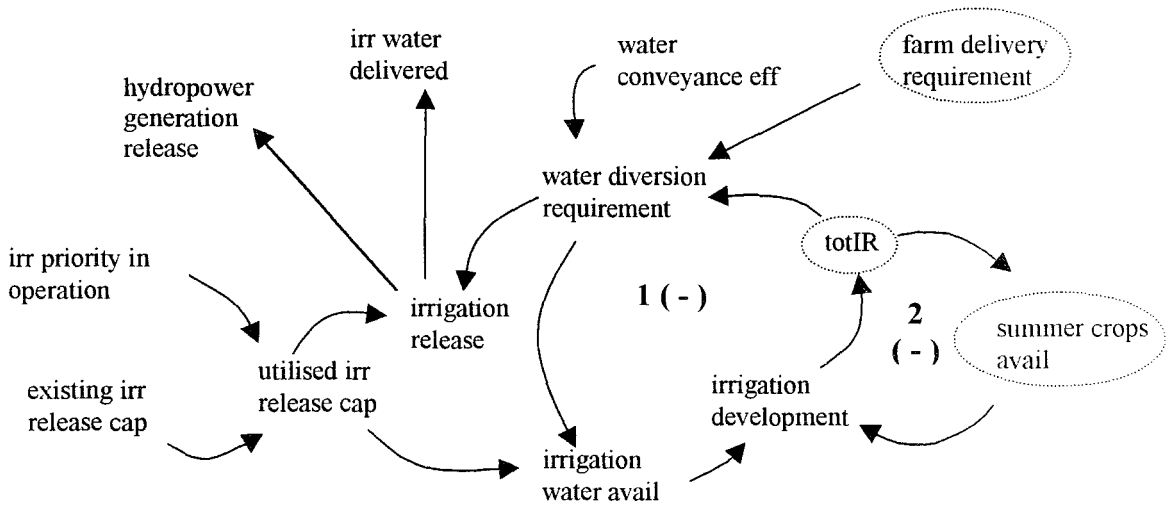


Figure 5.10. Causal loop diagram for water resources sector.

The stock-flow structure for GAPSIM water resources sector is presented in Figure 5.11.

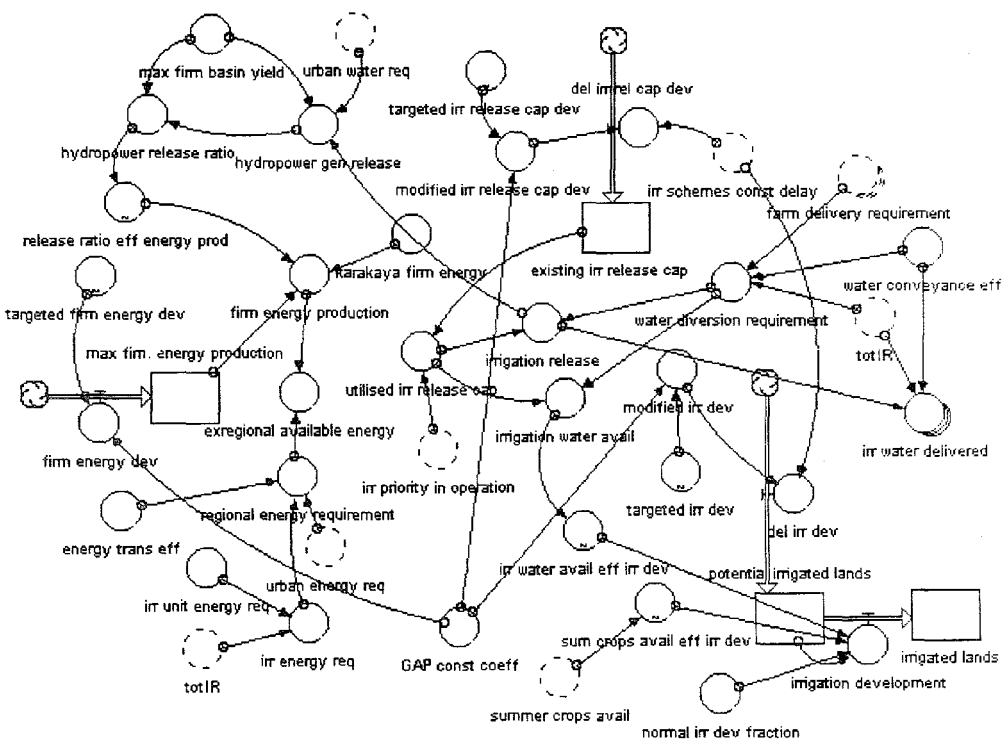
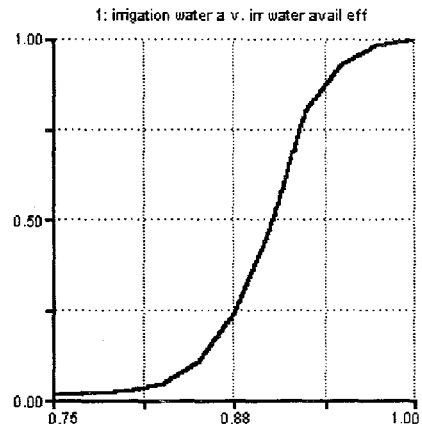


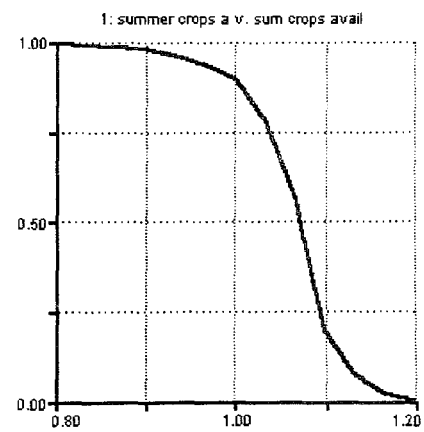
Figure 5.11. Stock-flow structure of water resources sector.

Water diversion requirement (m3/year) is calculated as a function of total irrigated lands (ha), water_conveyance_eff (unitless) and farm_delivery_requirement (mm/year) imported from irrigation and salinisation sector. Irrigation water delivered (mm/year), the variable exported the irrigation and salinisation sector is calculated as a function of irrigation_release (m3/year), total irrigated lands (ha) and water_conveyance_efficiency (unitless). Delivered water is shared among different farmlands and wine-garden in proportion with their delivery requirements.

The effect of irrigation water availability on irrigation development is formulated by a graphical function. It is assumed that decreasing availability of water will have increasing adverse affect on irrigation:



The effect of summer crops availability on irrigation development is hypothesized by the following functional form presented below:



Therefore,

irrigation_development=potential_irrigated_lands*normal_irr_dev_fraction*sum_crops_available_eff_irr_dev*irr_water_avail_eff_irr_dev (ha/year)

normal_irr_dev_fraction=1 (1/year)

V.2.5.2. Water Resources Sector Simulation Runs

In Figure 5.12, the verification of basic assumption of the water resources model about the trade-off between irrigation releases and hydropower production is demonstrated with a test run. When hydropower release (or in-stream flow) is equal to the maximum firm basin yield (35 billion m^3/year) and when all hydropower plants are in operation, firm hydropower production is 25 billion KWh/year, and when irrigation release are increased and hydropower release is dropped to the half of maximum firm basin yield (18 billion m^3/year), firm hydropower production is dropped to 18 billion KWh/year. When we subtract firm energy production of Karakaya hydropower plant (6.5 billion KWh/year) from both quantities, the ratio of the resultants 18.5 and 11.5 is equal to 0.62. Therefore, when hydropower release is halved, hydropower production is dropped by a factor of 60 % if we omit Karakaya hydropower plant. This result confirms with calculations in GAP Master Plan [50] and demonstrates that, the model formulation for the variable release_ratio_eff_energy_production is sufficient.

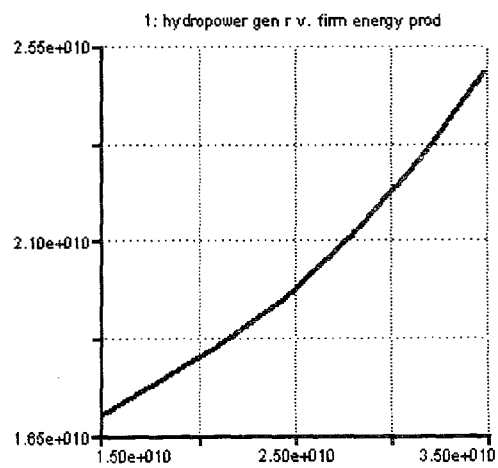


Figure 5.12. Hydropower generation release (m^3/year) verses hydropower production (KWh/year).

In Figure 5.13., increase in irrigated lands (ha), irrigation water availability (unitless) and regional firm energy production (KWh/year) with respect to different irrigation priority, GAP construction constant and water schemes construction delay are demonstrated by arable lands sectors and water resources sector runs. In the first run (a), there is no operational constraint on availability of irrigation water but as diversion requirement exceeds existing capacity, irrigation water availability decreases. But decreasing availability inhibits rate of transformation from rainfed lands to irrigated lands, so that, this negative feedback (first negative feedback in Figure 5.10.) avoids high irrigation water scarcity on irrigated lands. Firm energy production is stagnated at 15 billion KWh/year and irrigated lands do not reach the targeted value, 1.7 million ha.

In the second run (b), a higher operational constraint is applied for irrigation water in order to increase firm energy production. Therefore, only a portion of existing irrigation capacity is utilized. This time, firm energy production stagnates at 19 billion KWh/year but irrigated lands increase up to 900 thousand hectares in 40 years.

In the third run (c), after year 2000, the targeted construction rate for GAP is halved by setting GAP_const_coeff to 0.5. and project is accomplished at lower levels in terms of firm energy production, irrigation capacity and irrigated lands. In this run, firm energy production firm energy production reaches 15 billion KWh/year and total irrigated lands reach 1.1 million hectares.

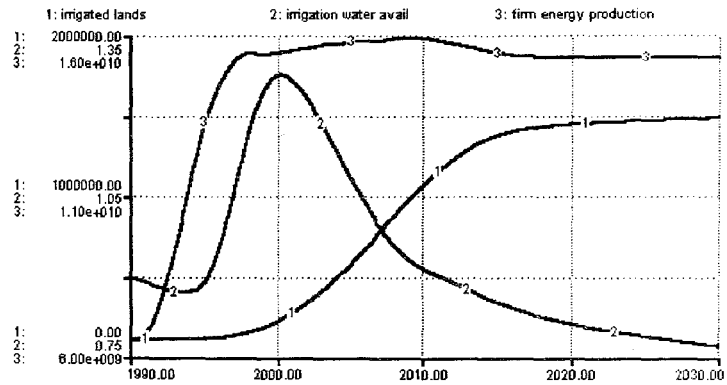
In the last run (d), a 10 years delay for development of irrigation schemes is applied. In this run, while firm energy production reaches to about 19 billion KWh/year in year 2010, soon it decreases because of the delayed increase in irrigated lands, which reaches to about 1.3 million hectares by year 2030.

(a)

irrigation priority in operation = 1

GAP construction coeff = 1

irr schemes const delay =1

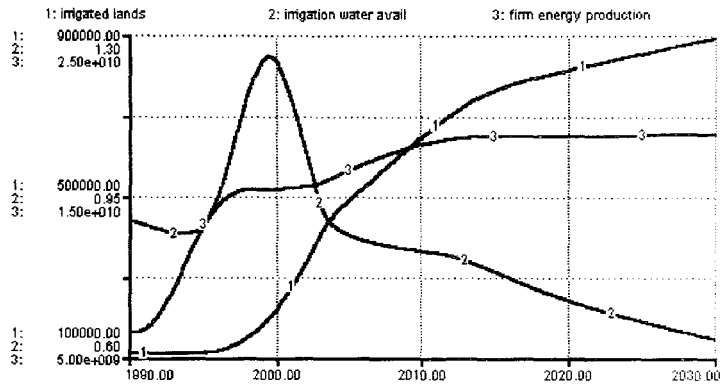


(b)

irrigation priority in operation = 2 (after year 2000)

GAP construction coeff = 1

irr schemes const delay =1

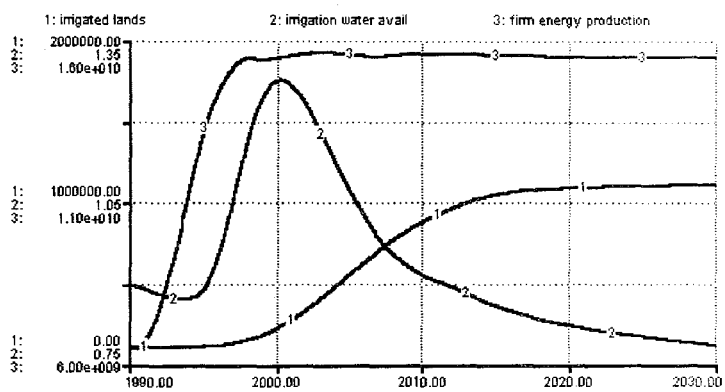


(c)

irrigation priority in operation = 1

GAP construction coeff = 0.5 (after year 2000)

irr schemes const delay =1



(d)

irrigation priority in operation = 1

GAP construction coeff = 1

irr schemes const delay =10

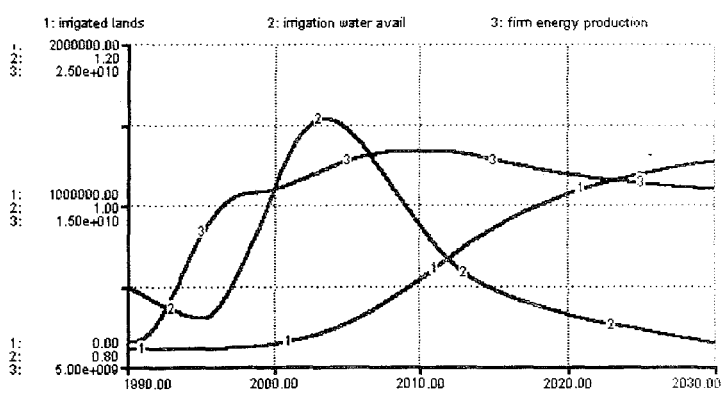


Figure 5.13. Sector isolated runs for arable lands and water resources sectors.

V.2.6. Fertilizers Sector

Inorganic fertilizers supplying major nutrients such as nitrogen, phosphorus and potassium minerals are crucial in modern agriculture. Though, there exists new trends in farming practices emphasizing appropriate management of animal manure and other farm residues as plant nutrient supply, commercially available cheap and easily applicable inorganic materials such as ammonium nitrate, ammonium sulfate, superphosphate, triple superphosphate etc., which have direct impact on farm yields still play an important role in agriculture. Increasing use of artificial fertilizers still, is the major and simplest practice in enhancing farm yields in transient technology agricultural systems, masking adverse effects of soil erosion on fertility [52].

In GAP, as mentioned in section V.2.1., artificial fertilizers consumption is very low, but certain norms for nitrogen and phosphate supply are proposed for crops in irrigated fields associated with corresponding yields (see section V.2.15.1). Potassium supplying materials are considered not to be essential for GAP fields [28].

Increasing use of artificial fertilizers are of great environmental concern because of their effect on eutrophication. While, adsorbed $H_2PO_4^-$ onto soil particles is carried along and deposited in surface waters as soil sediment because of erosion, dissolved NO_3^- and NH_4^+ is leached into groundwater and surface waters through infiltration and drainage systems. Nitrate pollution is a problem when more nitrogen fertilizer is added than crops and microorganisms can immobilize or absorb during growth [35].

V.2.6.1. Fertilizers Sector Description

Fertilizers sector in GAPSIM evaluates changing fertilizer application rates in different fields and amount of mineral nitrogen that will be leached from each field. While calculating the fertilizer quantities, it is assumed that, proposed application rates are the minimum and can be increased by the farmers as a reaction to decreasing yields in long term in order to sustain conventional yields. Though, farm management practices such as organic fertilization and tillage methods, soil organic matter and climate have effect on

nitrogen leaching, in this model a rough estimate of potentially leachable nitrogen as a function of fertilizer application quantity is used to calculate amount of mineral nitrogen leached with respect to different field stocks.

Fertilizers sector imports variables normal_nitrogen, normal_nitrogen_seconds, normal_phosphate and normal_phosphate_seconds from calculations sector and exports nitrogen_appl, phosphate_appl and fert_mult_norm_yield to arable lands sectors (see stock-flow structure in Figure 5.30).

The only stock variable in fertilizers sector is

percieved_yield_loss: yield loss perceived by the farmers (unitless), modeled as a five year delay of yield loss ratios calculated for each land stock in arable land sectors. Therefore, in the model, reaction to decreasing yields are not immediate but consistency is required.

Major converters are

yield_loss_eff_normal_fertilizers: effect of perceived yield loss on fertilizer quantities (unitless).

nitrogen_primary: amount of mineral nitrogen N applied on primary crops (kg/ha/year).

nitrogen_seconds: amount of mineral nitrogen N applied on second crops (kg/ha/year).

nitrogen_appl: total mineral nitrogen applied on fields and wine-garden (kg/ha/year).

phosphate_primary: amount of phosphate (P_2O_5) applied on primary crops (kg/ha/year).

phosphate_seconds: amount of phosphate (P_2O_5) applied on second crops (kg/ha/year).

phosphate_appl: total phosphate applied on fields and wine-garden (kg/ha/year).

fert_mult_norm_yield: effect of nitrogen fertilizer quantity on yields (unitless).

pot_prim_nit_leach_perc: percentage of mineral nitrogen applied on primary crops susceptible to leaching (unitless).

pot_sec_nit_leach_perc: percentage of mineral nitrogen applied on second crops susceptible to leaching (unitless).

pot_leach_nitrogen: total mineral nitrogen N potentially leachable (kg/ha/year).

farm_leach_constant: a constant indicating fraction of pot_leach_nitrogen leached through root zone (unitless).

nitrogen_leached: amount of mineral N leached through root zone (kg/ha/year).

In fertilizers sector, similar feedback loops act between different arable land yields and their associated fertilizer quantities which adjusts fertilizer application according to decreasing yields (Figure 5.14.). When yield loss follows long term consistency, so that it is perceived by the farmers, farmers tend to increase fertilizer consumption as it is the simplest and cheapest management practice. This is modeled by the variable yield_loss_effect_fertilizers which increases nitrogen primary and in turn, enhances yield through fert_mult_norm_yield, decreasing yield_loss_ratio, therefore, controlling the increase in fertilizer quantities. In the Figure, the variables circled with dashed arrows are imported from arable land sectors and the cut arrow represents information delay.

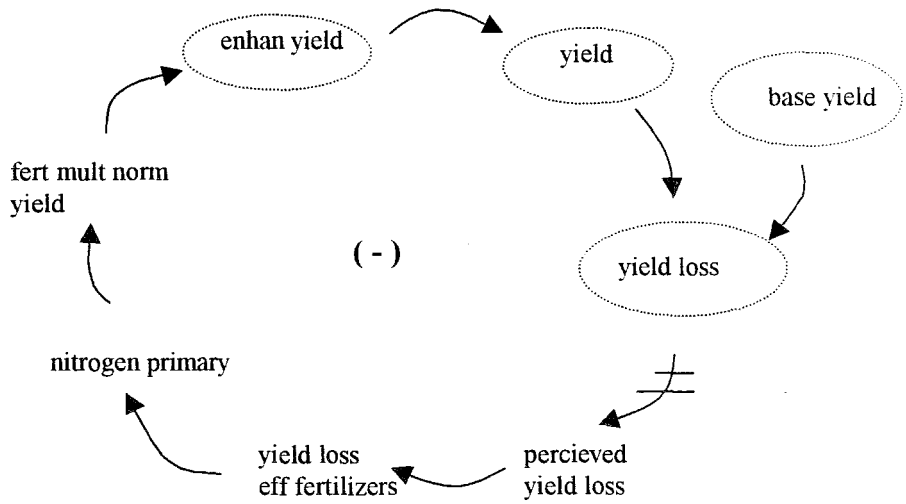


Figure 5.14. Causal loop diagram for fertilizers sector.

In Figure 5.15., stock-flow structure of fertilizers sector is presented.

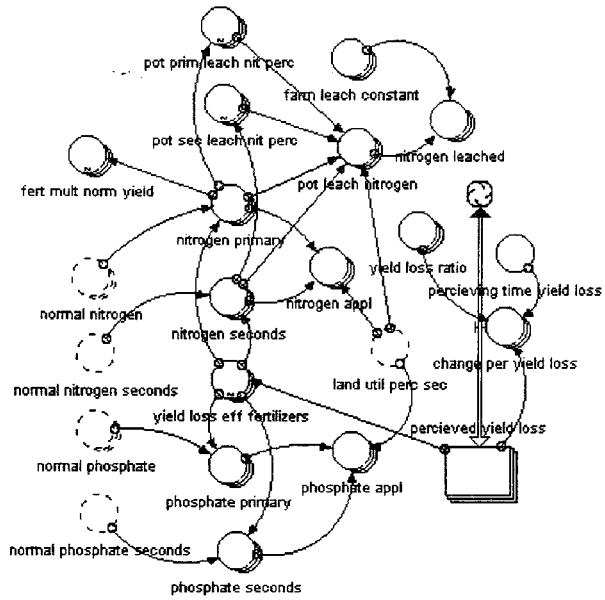
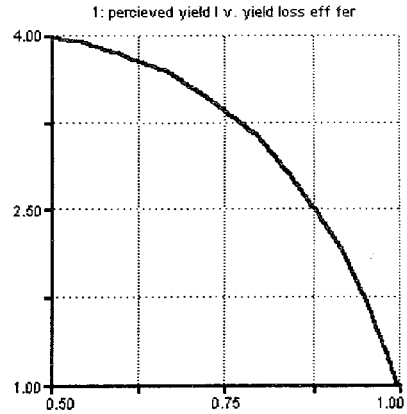


Figure 5.15. Stock-flow structure of fertilizers sector.

In fertilizers sector, yield_loss_eff_fertilizers is formulated according to consistent long term global evidence on fertilizer quantities especially in developed world. In regions where artificial fertilizers are used intensively, the detrimental impact of erosion on productivity can be masked [53]. Here, it is assumed that, yield losses in the scope of simulation except losses due to pests and water insufficiency which can obviously be detected by the farmers can be responded by increasing fertilizer consumption being the simplest and cheapest management practice. The graphical function below is constructed arbitrarily, assuming that perceived long term yield losses up to 50 % can gradually lead to increases in fertilizer quantities up to 400%:

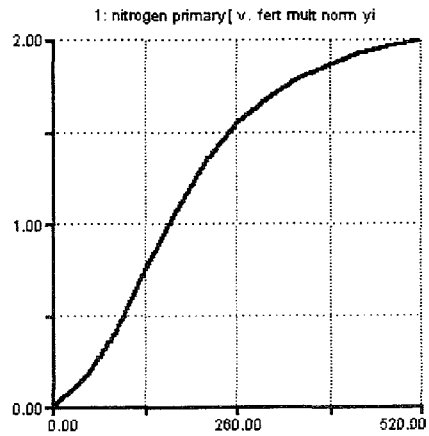


Nitrogen fertilization for primary and for secondary crops are calculated as

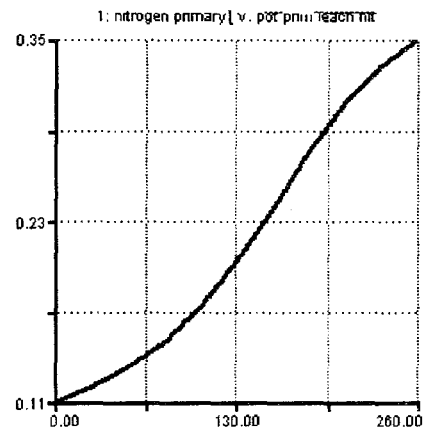
nitrogen_primary=normal nitrogen*yield_loss_eff_fertilizers (kg/ha/year)

nitrogen_second=normal_nitrogen_seconds*yield_loss_eff_fertilizers (kg/ha/year)

In static experimental analysis, where all soil conditions are tried to be controlled, yield response to fertilizer quantities obey the law of diminishing returns, i.e., additional units of fertilizer may result in a rapid increase in yield, then a leveling and further increases in fertilizer may give declining yields. Fertilizer application rates are proposed according to level where the last increment is just paid by the value of the increased yield [54]. This is called as the maximum economic rate of fertilization. In our model, during the simulation, since soil fertility changes because of erosion, fallow and salinisation, formulation of fert_mult_norm_yield differs from the behavior explained above. Though we do not have explicit data referring yield responses in the long term, global evidence suggests that increasing fertilizer application rates act to sustain conventional yields in arable lands. In the formulation of fert_mult_norm_yield, we assume that while actual and proposed fertilizer application rates have no effect on normal yields, quadrupling of this quantity results in 100 % increase. Fertilizers multiplier for normal yields on COIF is demonstrated below:



For any particular cropping system, higher fertilizer rates generally increase the level of N leached from root zone. However, there is not necessarily a proportionate reduction in N leached from a corresponding reduction in fertilizer rate applied. Application of fertilizer N in excess of the maximum economic rate of fertilization level dramatically increases N loss from the root zone [55]. While formulating the variables pot_prim_leach_nit_perc and pot_sec_leach_nit_perc, proposed fertilizer N quantities are taken to be %80 efficient, such that, %20 of mineral N is left susceptible to leaching and this percentage is increased exponentially with increasing rate of fertilizer application [35]. We present the formulation for COIF:



Potentially leachable nitrogen is calculated as summation of potentially leachable nitrogen from primary and secondary crops multiplied with corresponding land utilization percentage for seconds according to the following equation:

pot_leach_nit=(nitrogen_primary*pot_prim_leach_nit_perc)+(nitrogen_seconds*pot_sec_leach_nit_perc*land_util_perc_sec) (kg/ha/year)

But, fertilizer rate of application alone does not adequately explain the whole picture concerning N leaching. Crop choices and crop rotation patterns have a significant impact on the amount of N leached. Mineralization of organic N in the fall and early spring, periods during which plants are not assimilating N, can lead to NO_3^- accumulation in the soil and therefore, increase the potential for N leaching [55]. Experimental work in this field show that, significant proportion of annual leaching occur during bare soil and rainy periods on fertilized fields [56]. Therefore, an arbitrary constant, farm_leach_constant is used for each field stock representing different crop rotations to

calculate nitrogen_leached. For COIF and COSIF where all crops are harvested in autumn farm_leach_constant is taken to be 1 and for CESIF and CCSPIF where winter crops exist in farm rotations, it is taken to be 0.8. Leaching nitrogen is calculated by the equation

nitrogen_leached=pot_leach_nitrogen*farm_leach_constant (kg/ha/year).

V.2.7. Pesticides Sector

Pesticides use in agriculture is a debate involving environmental, economic and ethical dimensions. Defining pests in agricultural ecosystems, proper choice of crop protecting chemicals and determining their application rates is a dynamic problem since costs and benefits of pesticide use is subject to change in time by development of resistant species of pests and introduction of new chemicals into the market with different persistence levels and toxicity effects.

Essentially, the traditional methods of crop protection employed prior to World War II involved crop rotations, small fields of different crops and the integration of crops and livestock. Thus seasonality, crop susceptibility to disease, predation and competition, the use fallow and crop organization provided farmers with a number of permutations that could assist in pest control as well as maintenance of soil fertility. By the advent of artificial fertilizers and the onset of mechanization, agriculturalists began to look for alternative means of crop protection that would provide adequate safeguard for the increasing monoculture of crops in Europe and North America, which initiated use of crop protecting synthetic chemicals in agriculture [57].

According to global data, crop losses to pests increase despite intensified pesticide use, and among several reasons, the increase in pests that are resistant to pesticides, the reduction in crop rotations and the increase in monocultures and reduced crop diversity play major role in increasing losses [58]. Between 1945 and 1989, despite a tenfold increase in insecticide use in USA, crop losses to insects increased from 7 percent to 13 percent. Much of this is attributed to the development of monoculture and the abandonment of crop rotations [59]. Field researches on several irrigation schemes in Turkey support this fact. In "Büyük Menderes Havzası", since same crop is cultivated each

year and rotations are abandoned, pest population increase is observed, leading to increasing pesticide application rates, increasing costs and pollution [60]. In "Aşağı Seyhan Ovası", because of increasing costs of crop protection and problems related with waterlogging, farmers of Çukurova gradually tend to abandon cotton cultivation and prefer soya and maize [44].

Today, major pesticides in the market belong to the groups such as, organochlorines, organophosphates, synthetic pyretroids, carbamates, phenoxy compounds, benzimidozols, triazols and etc., all different by their persistencies and toxic effects in the environment, but, similar by their short term effect on reduction of pests and long term effect on pest resistance building. These chemicals are grouped under a broad category as "pesticides" in terms of effective material in statistics concerning aggregate pesticides consumption and aggregate yields. Despite introduction of alternative pest specific chemicals in the market, up to date, pest resistance management has been unsuccessful [61]. Resistance is exacerbated by insecticide overuse and acts as a stimulant for the pesticide industry. Since resistance is developed gradually, as the effect of pesticide decreases, farmers tend to increase pesticide application rates [62].

Unless, that wide set of pest control practices summarized under the term "integrated pest management" is applied or in built pest resistant crop varieties are introduced, pest increases due to monocultural farm systems and pest resistance development due to overuse of pesticides will be indispensable. Therefore, global pesticides dilemma will be in action. But, integrated pest management requires strict monitoring of pests and availability of know-how on many crop protection techniques including crop rotations, and in Turkey, it is far from application [62].

5.2.7.1. Pesticides Sector Description

GAPSIM pesticides sector evaluates annual pesticide application rates for each field and wine-garden stock with respect to changing intensity of monocultural activities and pest resistance development. During this calculation, it is assumed that, under those conditions where pest resistance development and pest intensification due to monoculture do not occur, normal pesticide application rates imported from arable lands calculations

sector results in nominal pest density, leading to null pesticides multiplier on enhanced yield. Hence, under these conditions, pesticides model is in equilibrium and normal pesticide application rates have no effect on enhanced yields in arable land sectors. But, second model assumption is that, by increasing cultivation periods of cotton and other summer crops and by increasing resistance of pests, farmers tend to increase pesticide application rates so that pest density, then, enhanced yields are controlled in acceptable limits.

Pesticides sector imports normal pesticide quantities from arable lands calculations sector and farm retention times from arable land sectors, and, exports actual pesticide application rates and pest_mult_enhan_yield to arable lands sectors.

Stock variables in pesticides sector are

pesticides_primary: pesticide application rate for primary crops (kg/ha/year).

percieved_pest_density: pest density perceived by the farmers, a two years information delay of pest_density (unitless).

Flow variables associated with these stock variables are

change_pesticides_primary: rate of change of pesticides_primary (kg/ha/year).

change_perc_pest_density: rate of change in perceived pest density (1/year).

Major converter variables in pesticides sector are

pest_density: a dummy variable indicating intensity of pests, ranging between zero and one (unitless).

nominal_pest_density: nominal value for variable pest_density leading to null effect on enhanced yields, taken 0.1 for each field and wine-garden stock (unitless).

per_to_nominal_pest_ratio: ratio of percieved_pest_density to nominal_pest_density (unitless).

fract_chan_pesticides_primary: fractional change of pesticide application rate for primary crops (1/year).

pesticides_appl: pesticide application rate for primary and second crops (kg/ha/year).

pesticides_eff_pest_density: short term effect of pesticides on pest_density (unitless).

pesticides_eff_pest_resist: long term effect of pesticides on pest resistance (unitless).

comb_ eff_pest_density: direct and long term effect of pesticides on pest density (unitless).

pot_farm_stay_time: variables imported from arable land sectors, an indicator of possible staying time of certain land portions under farm systems (years).

farm_stay_time_smoothed: the estimate for average staying time of farm systems calculated by a third order, 3 years smoothing of pot_farm_stay_time (years).

farm_stay_eff_pest_density: effect of staying time of certain farm systems on pest density (unitless).

pest_mult_enhan_yield: effect of pest density on enhanced yield of crops in arable land sectors (unitless).

In pesticides sector, three causal loops act, one of them reinforcing and two of them controlling pest_density (see Figure 5.16.). As the pest density increases, it is perceived by the farmers with a delay and the ratio of perceived pest density to nominal pest density acts as a stimulus to increase pesticide application rates (pesticide_primary). Pesticide application rate in the model has two effects on pest density. Increasing pesticide application rates control pest density by the variable pesticides_eff_pest_density which constitutes the first negative feedback loop. On the other hand, increasing pesticide application rates stimulate pest resistance development with a delay by the variable pesticides_eff_pest_resist and this constitutes the positive feedback loop further increasing pest density. Also, there exists a third loop (second negative feedback loop) which controls pest density by the variable farm_stay_eff_pest_density. As the pesticides application rate (pesticides_primary) increases, it affects unit_profit_COIF through a succession of causalities about farm economies and reduces profitability of COIF. Changing profitability stimulates increased rate of change in between land stocks which reduces potential farm stay times and then farm stay effect on pest density. This reduces pest density and pesticides application rates constituting the second negative feedback loop. In the Figure, cut arrows represent information delays and variables enclosed with dashed curves belong to arable lands sectors.

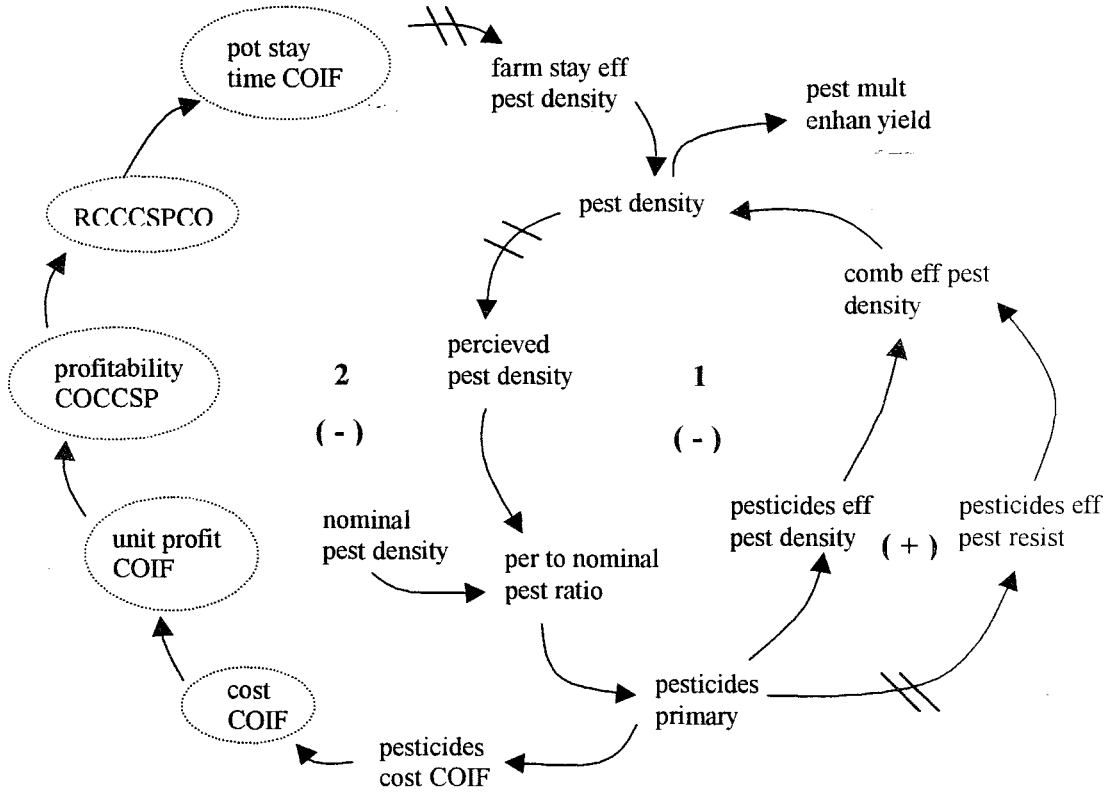


Figure 5.16. Causal loop diagram for GAPSIM pesticides sector.

Simplified stock-flow structure for pesticides sector is presented in Figure 5.17.

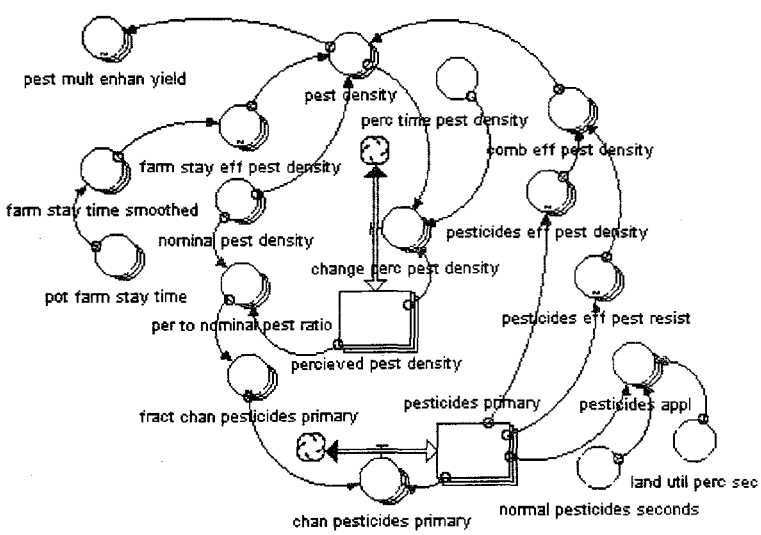
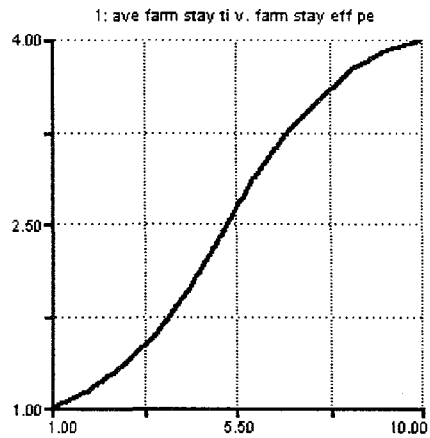


Figure 5.17. Stock-flow structure for GAPSIM pesticides sector.

While formulating farm_stay_eff_pest_density, it is assumed that, for cotton monoculture (COIF) and irrigated wine-garden (IRWG), pest density may increase by a factor of four if farm_stay_time_smoothed, which is taken as an average measure of monoculture period exceeds 10 years:



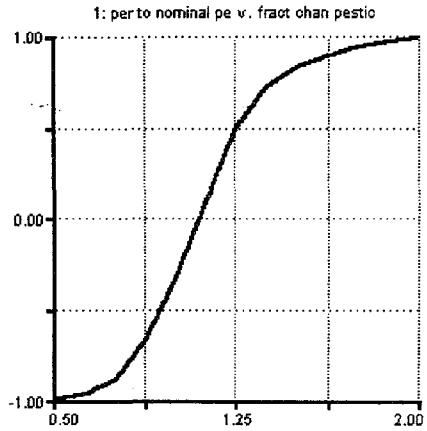
For COSIF and CESIF, farm staying effect has the same functional form but has mild limits, and for CCSPIF and rainfed arable land stocks this effect is canceled. Cotton-cereals-pulses-summer crops rotation system (CCSPIF) provides the ground for effective pest management.

According to historical evidence, farmers response to increasing pests is to increase pesticides application rate. For the formulation of this fact, ratio of perceived pest density (two years information delay of pest density) to nominal pest density is taken to be the stimulus which creates increase in pesticide application rate. It is assumed that, if perceived pest density is two times nominal density, farmers double and if perceived pest density is half of nominal pest density, farmers half the pesticide application rates. The formulation is as follows:

pesticides_primary(t)=pesticides_primary(t-1)+chan_pesticides_primary (kg/ha/year)

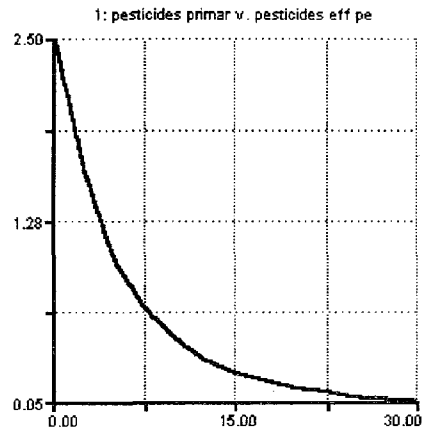
chan_pesticides_primary=pesticides_primary*fract_chan_pesticides_primary (kg/ha/year^2)

The variable fract_chan_pesticides_primary is formulated as a function of per_to_nominal_pest_ratio according to the relationship given below:



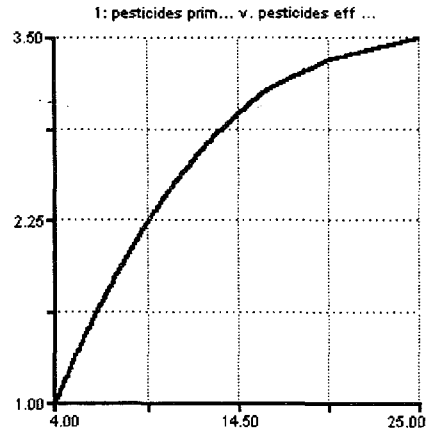
per_to_nominal_pest_ratio=percieved_pest_density/nominal_pest_density (unitless)

Effect of pesticide application rate on pest density is modeled by two variables, pesticides_eff_pest_density and pesticides_eff_pest_resistence. It is assumed that if we cut pesticide use, pest density may increase by a factor of 2.5 and if we further increase pesticides, we get diminishing returns and can destroy almost all pests. The formulation of this variables for COIF as a function of pesticide application rate is given below:



Also, as the pesticide application rate increases, pests respond by developing resistance. This is modeled as a five years third order delayed effect of pesticides application rate. Formulation is given below:

pesticides_eff_pest_resist=F(SMTH3(pesticides_primary,5,1) (unitless)



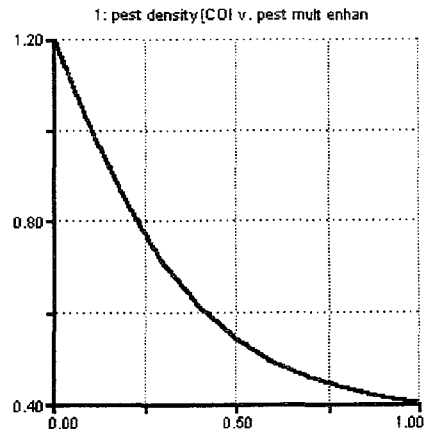
By this functional relationship it is assumed that, pest resistance can inhibit pesticides effect on pests creating a combined effect of pesticides on pest density.

comb_eff_pest_density=pesticides_eff_pest_density*pesticides_eff_pest_resist (unitless)

Then, pest density is calculated as factor of farm retention time and pesticides application rate on nominal pest density.

pest_density=nominal_pest_density*farm_stay_eff_pest_density*comb_eff_pest_density (unitless)

Effect of pests on farm yields are modeled by the variable pest_mult_enhan_yield, based on the assumption that nominal pest density has no effect on enhanced yields but if we destroy all pests we can increase enhanced yields by a factor of 1.2 and if pest density reaches its maximum value, enhanced yields drop by a factor of 0.4. The formulation of the variable as a function of pest_density is presented below:



Finally, pesticide application rate involving application for second crops is calculated and exported to arable land sectors for cost calculations

pesticides_appl=pesticides_primary+normal_pesticides_seconds*land_util_perc_sec (kg/ha/year)

V.2.7.2. Pesticides Sector Simulation Runs

In pesticides sector, since for pesticide application rates below 4 kg/ha/year pest resistance development is ignored and since for rainfed fields and wine-garden, farm staying effect on pest density is ignored, pesticide application rates for CERF, CEPRF and RFWG stay at normal pesticide quantities. Therefore, GAPSIM pesticides sector concentrate on irrigated fields and wine-garden. In Figure 5.18., isolated runs for pesticide application rates (kg/ha/year) are demonstrated. In the first run (a), both resistance development and farm staying effect are omitted, therefore, the model behaves as if there is continous rotation of crops. If resistance development effect was incorporated, the behavior generated would be the same as a logical consequence of the fact that, whenever there exists continous rotation of crops, there would be no chance for the pests to build resistance since they would be destroyed with previous years crop.

In the second run (b), both resistance development and farm staying effect are incorporated. In all the runs, pest densities are sustained around the normal level (0.1) so that pest effect on enhanced yields are kept constant. In this run, farm staying effects (constant in the isolated run) stimulate pesticide application rates to sustain pest density, therefore pest effect on yields.

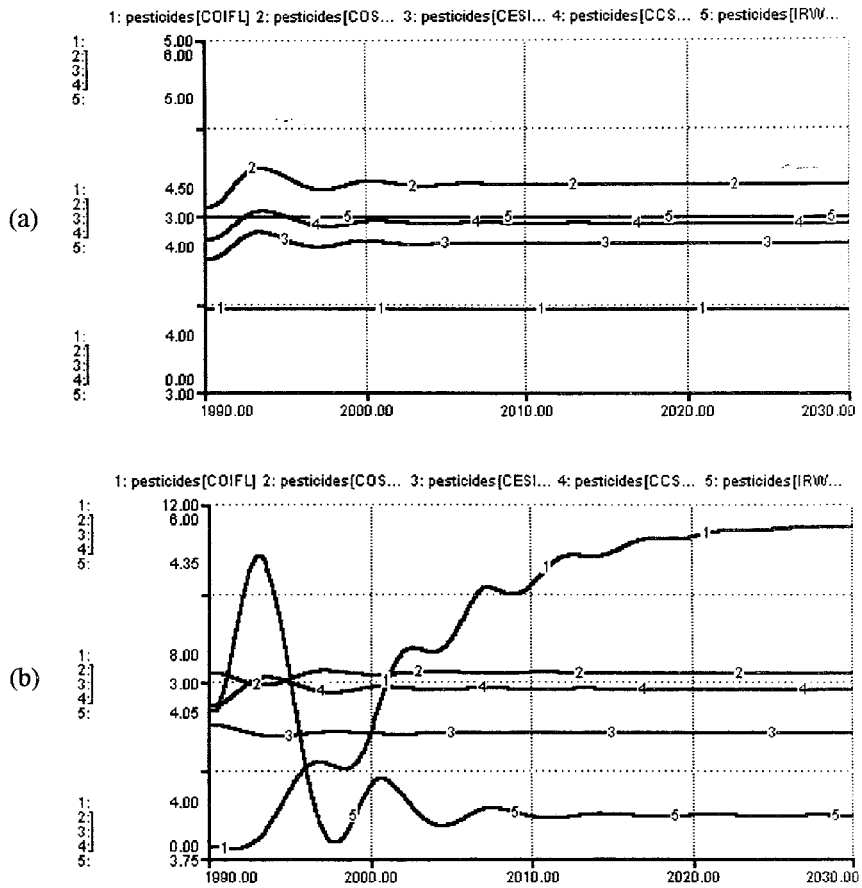


Figure 5.18. Sector isolated runs for GAPSIM pesticides sector.

V.2.8. Rangelands and Livestock Sector

In GAP region, mixed farming system is dominant, i.e., every undertaking has some cattle and sheep. Since fodder production is low, livestock is fed by crop residues and hay or they are fed on fallow areas and poor rangelands. About 9 % of farmers deal with food production alone [2]. Also, in recent years, there has been an increase in the number of rural families dealing only with livestock production and except nomadic tribes, about 9% of farmers began to deal only with livestock production [63]. Main feeding system in the region for cattle is such that, the herd in a community is gathered everyday by the herdsman and fed on rangelands and at the end of the day, cattle are distributed to their farms where they are fed with farm residues etc. [4]. For sheep, livestock are kept in the highlands during summer and in the plains during winter. Spring and autumn seasons constitute the pasturing period which the livestock travel between these places [64]. Hence,

both for sheep and cattle, livestock travel between farm and ranges and they are fed on both.

In GAP region, though there is a significant decrease in their population, there exists nomadic tribes with an estimated population of 200 thousand and with an estimated herd size of about 2 million sheep [63]. These Figures are not involved in official statistics.

Rangeland quality and herd size are of environmental concern because, when the carrying capacity of rangelands are exceeded by the herd load, overgrazing may result in barren soil which is susceptible to erosion, and erosion, in turn, inhibits regeneration process of rangelands, further increasing the effect of overgrazing on land degradation.

V.2.8.1. Rangelands and Livestock Sector Description

Rangelands and livestock sector in GAPSIM evaluates livestock load and its effect on soil erosion on GAP rangelands under changing herd sizes and range qualities. The sector consists of three stock variables representing rangeland sizes of different qualities and two stock variables representing relative weight of livestock on farms and ranges (see stock-flow structure in Figure 5.20.). In the model all livestock is converted to its sheep equivalent in terms of its productivity and feed requirements. Changing rangeland quality is modeled through flows between different rangeland stocks and changing livestock load on rangelands is modeled through flows between livestock quantities.

The stock variables in GAPSIM rangelands and livestock sector are

sheep_on_farm: sheep equivalent of livestock fed on farms (sheep). One to five is taken to be the conversion factor between cattle and sheep. 40000 sheep is taken to be the initial value for sheep on farm since available data about fodder areas of GAP fields suggests that only this much sheep can be fed on farms [4].

sheep_on_range: sheep fed on rangelands (sheep). Sheep equivalent of total livestock in the region except those of nomadic tribes' is estimated as 11.5 million [4].

rich_rangelands: those rangelands with high carrying capacity which are not susceptible to erosion (ha). Total rangelands in GAP is estimated as about 2.5 million hectares [4]. Initial value for rich rangelands is arbitrarily 0.8 million ha.

poor_rangelands: those rangelands with low carrying capacity which are susceptible to erosion (ha). Initial value is arbitrarily 1.1 million ha.

destroyed_rangelands: destroyed rangelands with no carrying capacity and high erosion susceptibility (ha). Initial value is arbitrarily 0.5 million ha.

Flow variables are

shift_range_to_farm: rate of shifting sheep load from rangelands to farms (sheep/year).

shift_farm_to_range: rate of shifting sheep load from farms to rangelands (sheep/year).

switch_sheep_to_non_fod: rate of switching from sheep production on farmlands to non-fodder crop production activities (sheep/year).

rich_range_dest: rate of rich rangeland destruction to poor rangeland (ha/year).

poor_range_dest: rate of poor rangeland destruction to destroyed rangeland (ha/year).

dest_range_impr: rate of destroyed rangeland improvement to poor rangeland (ha/year).

poor_range_impr: rate of poor rangeland improvement to rich rangeland (ha/year).

poor_range_to_rff: rate of conversion of poor rangelands to rainfed fields (ha/year).

dest_range_to_rff: rate of conversion of destructed rangelands to rainfed fields (ha/year).

Major converters in rangelands and livestock sector are

rich_range_carrying_capacity: maximum number of sheep unit rich rangeland can sustain. This constant is taken as 6 (sheep/ha) [31].

poor_range_carrying_capacity: maximum number of sheep unit poor rangeland can sustain, taken as 2.5 (sheep/ha) [31].

range_load_pot: range loading potential, maximum number of sheep rangelands can sustain without exceeding carrying capacity (sheep).

range_crowding: ratio of sheep_on_range to range_load_potential (unitless).

crowd_eff_range_dest: effect of crowding on rangelands destruction (1/year).

rich_range_norm_dest_fract: rich range normal destruction fraction, fraction of rich rangeland destructed each year, under conditions where grazing is below carrying capacity (1/year).

poor_range_norm_dest_fract: poor range normal destruction fraction, fraction of poor rangeland destructed each year under conditions where grazing is below carrying capacity (1/year).

dest_range_norm_regen_time: destructed rangelands normal regeneration time (year), this variable is adjusted as 200, assuming almost no regeneration for destroyed rangelands.

poor_range_norm_regen_time: poor rangelands normal regeneration time (year), this variable is taken as 30 years.

eros_mult_range_regen: a variable imported from erosion sector indicating current status of erosion on rangelands regeneration (unitless).

poor_range_imp_fract: a fraction imported from governmental sector indicating government policy on poor rangelands improvement (1/year).

range_fract_conv_fields: fractional conversion of rangelands to fields created by population density on rainfed fields (1/year).

crowding_eff_conv_fields: effect of crowding on rangelands conversion to rainfed fields (unitless).

norm_trans_fract_range_to_farm: normal transfer fraction from sheep on range to sheep on farm, 0.02 (1/year).

norm_trans_fract_farm_to_range: normal transfer fraction from sheep on farm to sheep on range, 0.5 (1/year).

crowd_eff_range_to_farm: effect of rangeland crowding on sheep transfer from range to farm (unitless).

crowd_eff_farm_to_range: effect of rangeland crowding on sheep transfer from farm to range (unitless).

cost_ratio_fodder_to_grass: ratio of fodder_unit_cost to range_grass_unit_cost (unitless).

cost_ratio_mult_range_to_farm: effect of cost_ratio_fodder_to_grass on sheep transfer from range to farmlands (unitless).

cost_ratio_mult_farm_to_range: effect of cost_ratio_fodder_to_grass on sheep transfer from farm to rangelands (unitless).

inome_sheep_on_farm: aggregate income generated by sheep on farm in terms of milk and livestock (TL/year).

cost_sheep_on_farm: aggregate cost of sheep on farmlands in terms of fodder consumption (TL/year).

profitability_sheep_on_farm: ratio of income_sheep_on_farm to cost_sheep_on_farm (unitless).

sheep_to_non_fod_prof_rat: ratio of profitability_sheep_on_farm to profitability of non fodder field crops which is calculated in arable lands calculations sector (unitless).

fract_change_sheep_to_non_fod: fractional change created by sheep_to_non_fod_prof_rat on sheep on farm (1/year).

livestock_potential: a potential livestock quantity whose certain portion is switched to sheep on farm (sheep).

fodder_cons_sheep_on_farm: quantity of fodder consumed by sheep on farmlands (kg/year).

fodder_pot_ut_rat: fodder potential utilization ratio, ratio of fodder consumption of sheep on farm to regional fodder potential calculated in arable land calculations sector (unitless).

fodder_pot_ut_eff_switch_sheep: effect of fodder potential utilization ratio on rate of switching between sheep on farm and non fodder field crops (unitless).

In rangelands and livestock sector several loops act between sheep and rangelands, between sheep and market and between rangelands and population (see Figure 5.19.). One of these feedback loops is a dangerous positive feedback acting on range destruction rates. As range crowding increases, rate of range destruction increases creating decrease in rangelands (for example poor rangelands) and in range loading potential. This further increases range crowding and constitutes the positive feedback loop [18]. Other feedback loops are negative feedbacks increasing the stability of the system. Through the first three negative feedback loops range crowding control the further increase sheep on range and further decrease in range loading potential. In the first loop, as the quantity of sheep on rangelands increases, range crowding increases, but this controls sheep on

rangelands because, as crowding increases, people tend to shift their animal from rangelands to farmlands [18]. In the second loop, as sheep on range increases, range crowding increases and then people tend to give up ranging and reduce sheep on rangelands. In the third loop, as range crowding increases, this creates a resistance for land conversion to rainfed fields and avoids further decrease in rangelands through conversion to fields. Two negative feedback loops act between market and sheep on farmlands (loops 4 and 5). As the sheep on farmland increases, quantity of livestock marketed from farmlands increases and this affects livestock availability in the market. As availability is a direct indicator of price change in the market, increasing sheep on farm results in decreasing livestock price and decreasing profitability of sheep on farm. This affects sheep to non fodder field crops profit ratio and hence, rate of switching between sheep on farm and non fodder field crops. This constitutes the fourth negative feedback loop. Also, as the quantity of sheep on farm increases, land fodder in field sectors increases and land for non fodder crops decreases. As marketed quantity of non fodder crops decreases, in interaction with the market, price of non fodder field crops and profitability of non fodder field crops increases. This affects sheep to non fodder crops profit ratio and rate of switching from sheep on farm to non fodder field crops, constituting the fifth loop. Sixth negative feedback controls the increase in sheep on farmlands. As the regional fodder potential is consumed by sheep on farmlands, fodder potential utilization ratio increases and rate of switching from non fodder crops to sheep on farmlands is controlled by a converter, fodder potential utilization effect.

Also, there exists a seventh negative feedback loops acting on the conversion rate of rangelands to rainfed fields. Finally, as more rangelands are converted to rainfed fields, population density on rainfed fields reduce and conversion of rangelands to rainfed fields decrease by the variable range_fract_conv_fields.

In Figure 5.19., variables enclosed with circles represent variables belonging to other sectors of the model.

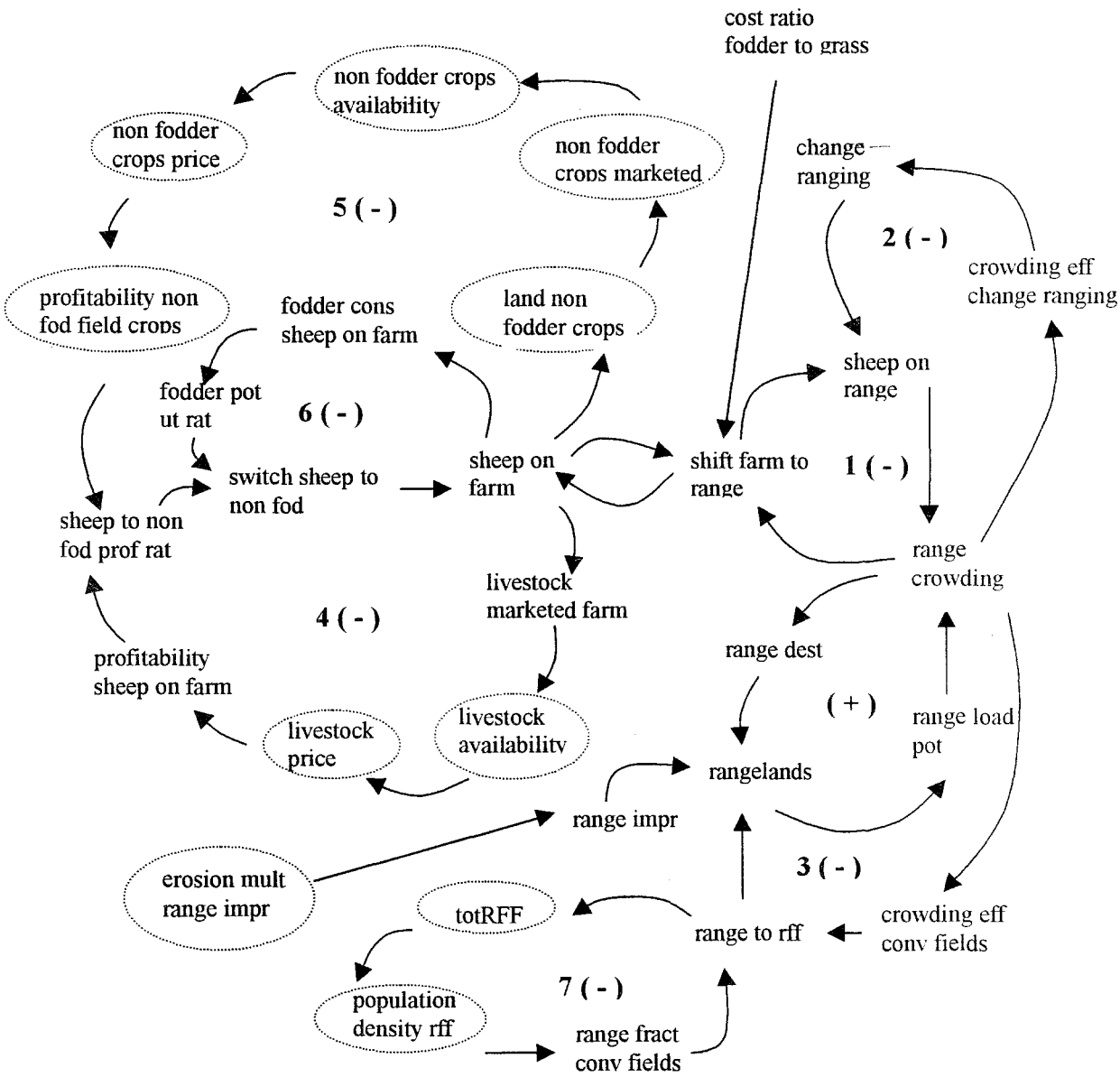


Figure 5.19. Causal loop diagram for rangelands and livestock sector.

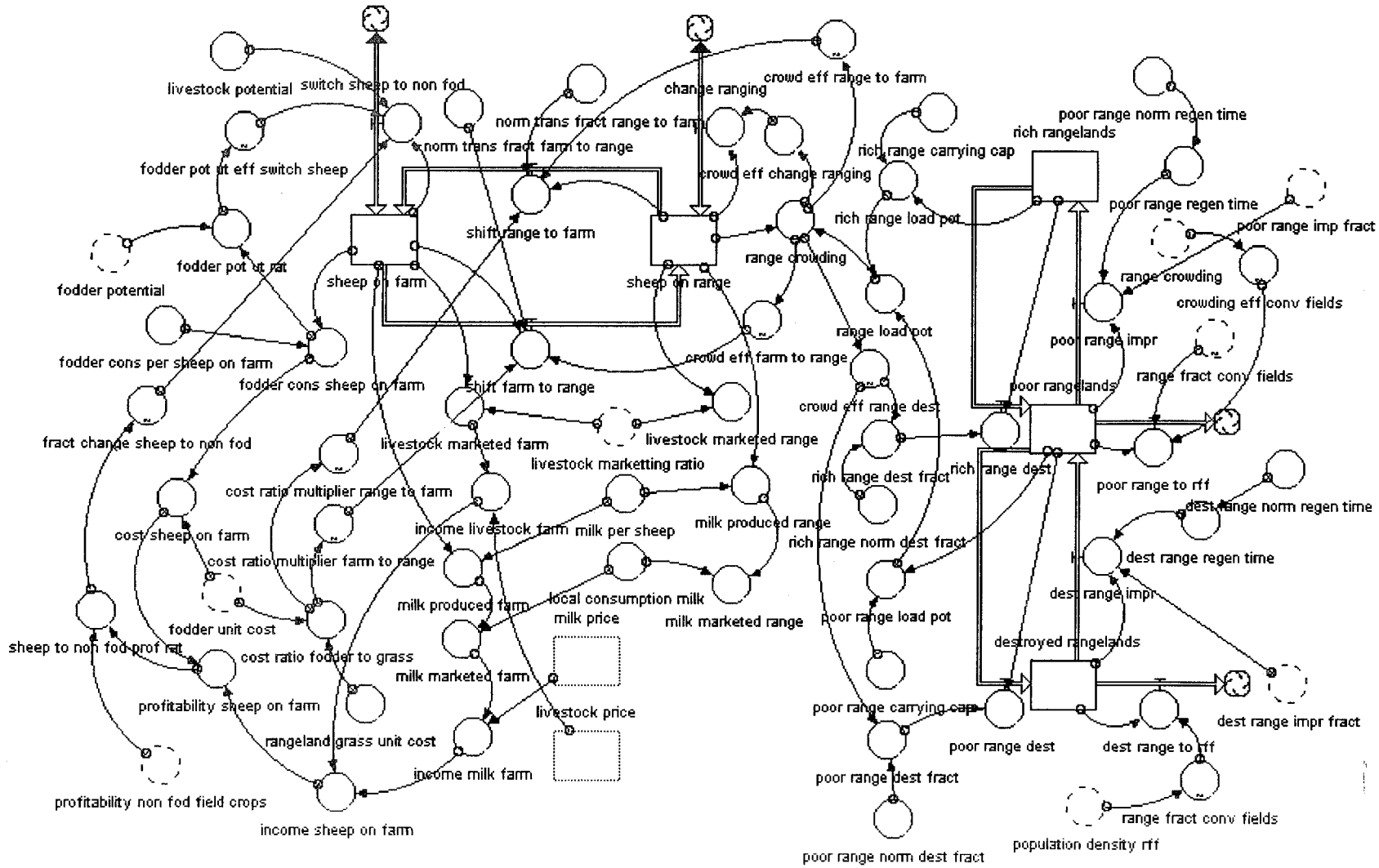


Figure 5.20. Stock-flow structure of GAPSIM rangelands and livestock sector.

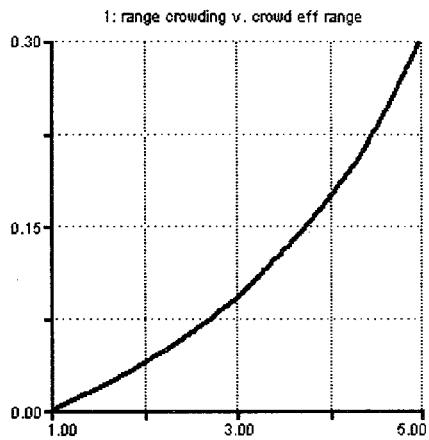
In rangelands and livestock sector calculations for size of any rangeland stock is made as follows:

rich_rangelands(t)=rich_rangelands(t-1)+(poor_range_impr-rich_range_dest)*dt (ha)

rich_range_dest=rich_rangelands(t-1)*rich_range_dest_fract (ha/year)

rich_range_dest_fract=rich_range_norm_dest_fract+crowd_eff_range_dest (1/year)

The variable crowd_eff_range_dest is formulated as a function of range_crowding, assuming that increasing crowding leads to increasing destruction rate:



where

range_crowding=sheep_on_range/range_load_pot (unitless)

poor_range_impr=poor_rangelands/poor_range_regen_time+poor_rangelands*poor_range_imp_fract (ha/year)

poor_range_regen_time=poor_range_norm_regen_time/eros_mult_range_regen (years)

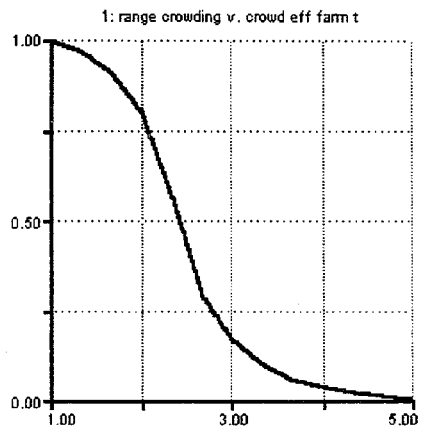
Functional form of erosion_mult_range_impr is given in erosion sector. Formulation of other flows related with rangeland stocks are similar to the above formulations.

In calculations of sheep_on_range, two effects, crowding and cost ratio of fodder unit cost to rangeland grass unit cost is considered.

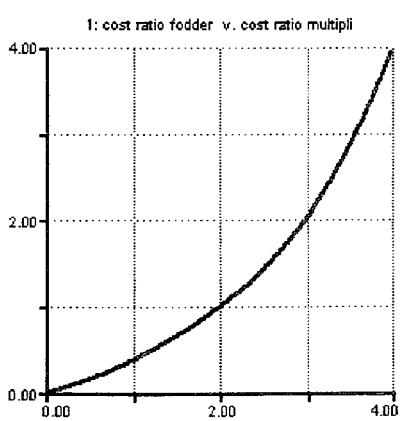
sheep_on_range(t)=sheep_on_range(t-1)+(shift_farm_to_range-shift_range_to_farm+change_ranging)*dt (sheep)

shift_farm_to_range=norm_trans_fract_farm_to_range*crowd_eff_farm_to_range*cost_ratio_mult_farm_to_range (sheep/year)

The variable crowd_eff_farm_to_range is formulated as a function of range_crowding. When range_crowding approaches to 5, transfer from farmlands to rangelands stops:



The variable cost_ratio_mult_farm_to_range is an effect of cost_ratio_fodder_to_grass on sheep transfer. With increasing fodder_unit_cost people tend to shift their animal towards rangelands and by increasing rangeland_grass_unit_cost, rate of transfer from farmlands to rangelands decrease:



where

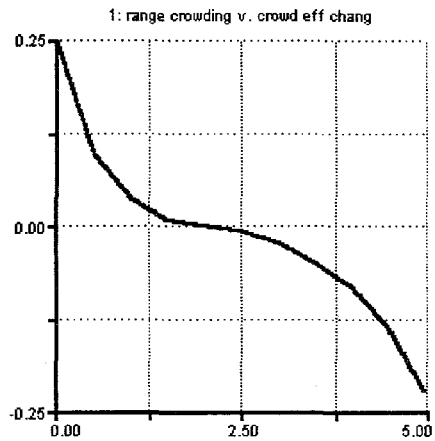
cost_ratio_fodder_to_grass=fodder_unit_cost/rangeland_grass_unit_cost (unitless)

The formulation of shift_range_to_farm involves the similar multipliers with shift_farm_to_range based on the same assumptions.

The variable change_ranging is formulated as a function of range_crowding.

change_ranging=sheep_on_range*crowd_eff_change_ranging (sheep/year)

and crowding_eff_change_ranging is formulated as a function of range crowding:

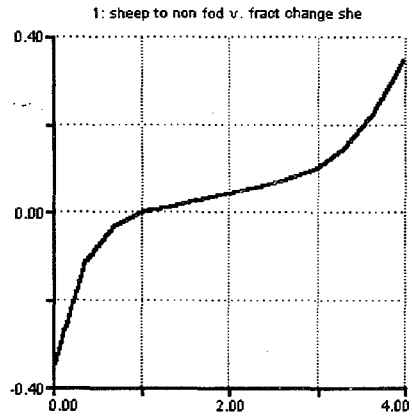


Increase or decrease in sheep on farmlands is modeled through biflow variable switch_sheep_to_non_fod related with sheep_on_farm, which represents the decision of decreasing land for non fodder crops in the favor of increasing livestock, therefore, fodder production areas.

sheep_on_farm(t)=sheep_on_farm(t-1)+(switch_sheep_to_non_fod+shift_range_to_farm-shift_farm_to_range)*dt (sheep)

switch_sheep_to_non_fod=IF(fract_change_sheep_to_non_fod>=0)THEN(livestock_potential*fract_change_sheep_to_non_fod*fodder_pot_ut_eff_switch_sheep)ELSE(sheep_on_farm*fract_change_sheep_to_non_fod) (sheep/year)

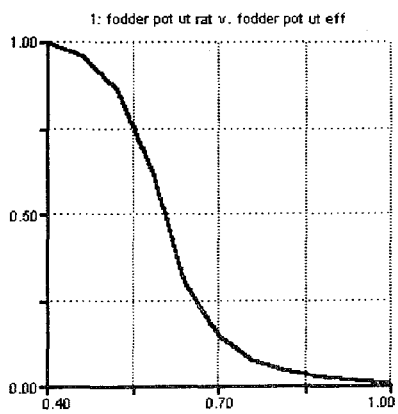
The variable fract_change_sheep_to_non_fodder is a function of sheep_to_non_fod_profit_ratio which is taken as an aggregate measure of relative advantage of sheep production on farmlands to non fodder crops production in terms of their profitability:



and

sheep_to_non_fodder_profit_ratio=profitability_sheep_on_farm/profitability_non_fod_field_crops (unitles)

Second effect controlling the switch from sheep on farm to non fodder crops production is the multiplier fodder_pot_ut_eff_switch_sheep, which is a function of regional fodder potential utilisation. When regional fodder potential is close to full utilisation by sheep on farm, this multiplier inhibits the flow switch_sheep_to_non_fod when it is positive:



fodder_pot_ut_rat=fodder_cons_sheep_on_farm/fodder_potential (unitless)

V.2.8.2. Rangeland and Livestock Sector Simulation Runs

In Figure 5.21., behavior of rangeland stocks (ha) under no-crowding and no governmental improvement conditions are demonstrated. Therefore, if we avoid crowding, a gradual regeneration should be possible, such that, poor and destroyed rangelands will decrease and rich rangelands will increase.

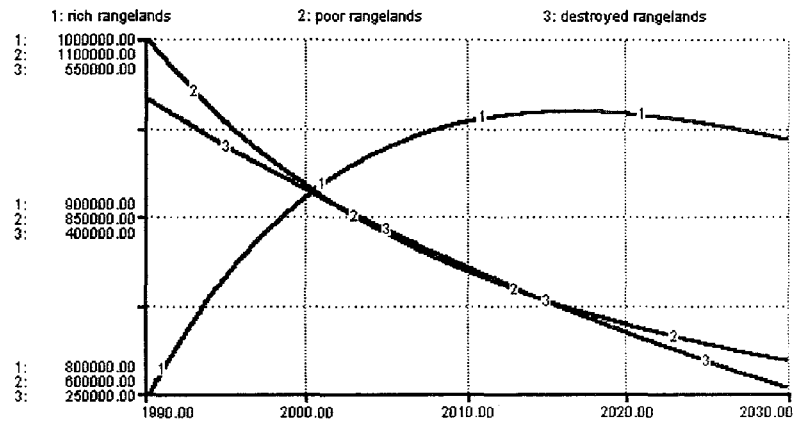


Figure 5.21. Sector isolated run for rangelands where effect of crowding is omitted.

In Figure 5.22., isolated runs for rangelands (ha) and livestock (sheep) are demonstrated where no precautions are taken for protection of rangelands. The first graph shows that there exists a strong increase in quantity of destructed rangelands. Sheep on rangelands also decline with decreasing rangelands.

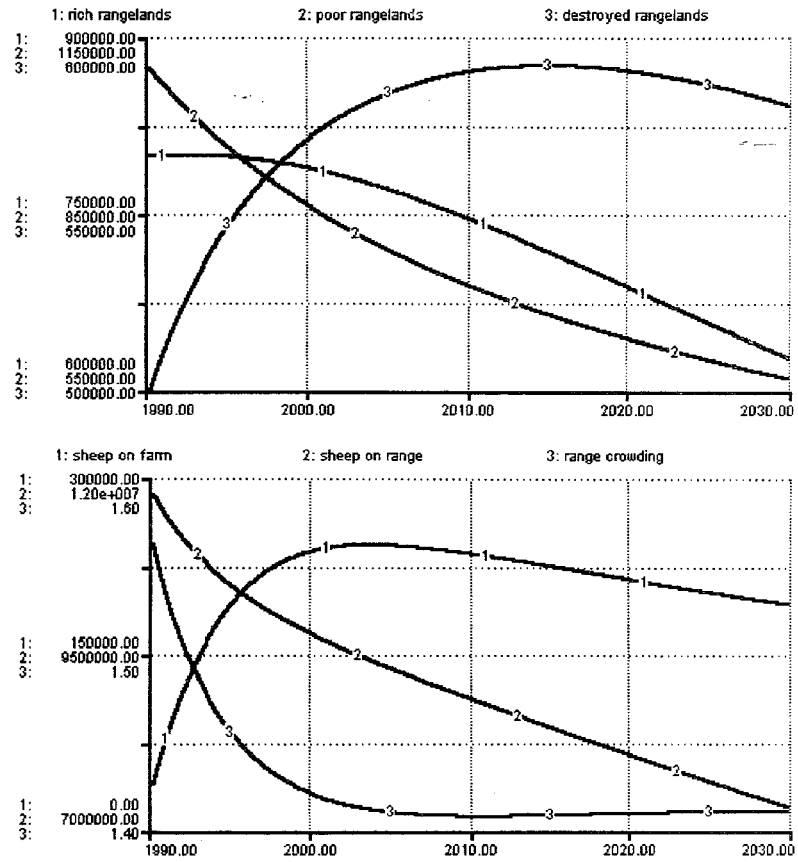


Figure 5.22. Sector isolated runs for rangelands and livestock sector.

In Figure 5.23., a rangelands protection policy, cost application for rangeland grass is simulated. The aim of this policy is to decrease transfers from farmlands to rangelands and to increase transfers from rangelands to farmlands. Therefore, sheep on rangelands will decrease and yield lower crowding values which weakens the positive feedback. This policy further decreases the sheep on rangelands and rangelands begin to get improved after year 2010 as crowding is decreased.

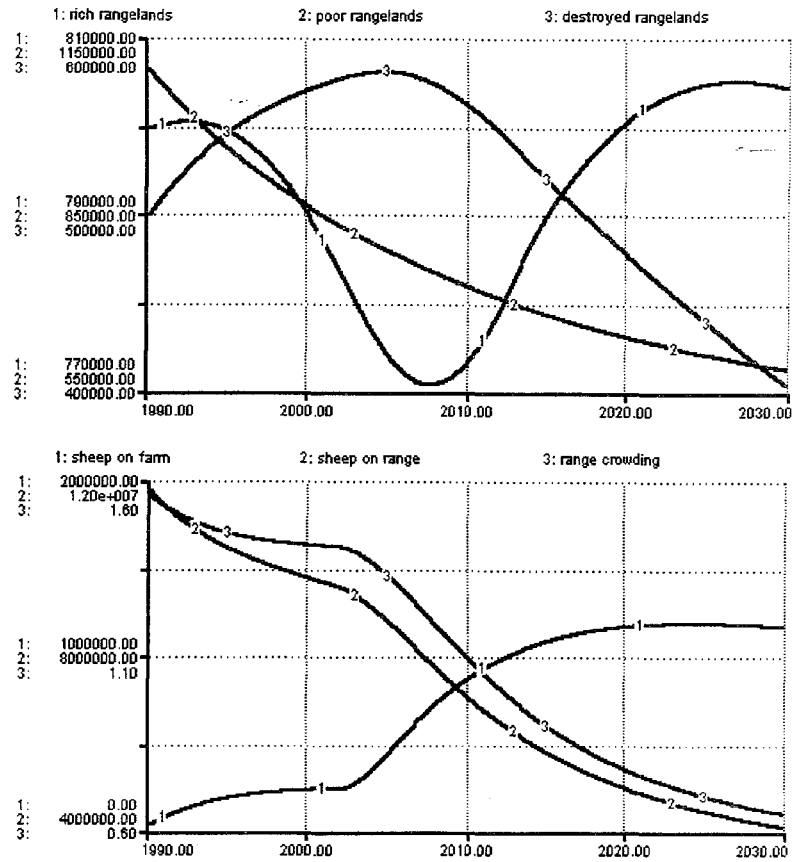


Figure 5.23. Sector isolated runs for rangelands and livestock under high range grass costs.

V.2.9. Forests Sector

Forests of GAP region are classified as grove, poor heath and rich heath. Official forestry policies are based on this classification, where heathlands are considered as sources of firewood supply and groves as sources of timber supply [4]. According to the national forestry plan, (1990 - 2009), forests of GAP region add up to about 1.1 million hectares but only about 48000 ha of this land is grove and about 280000 ha is rich heath, while 870000 ha is poor heath where susceptibility to soil erosion is high [4]. Though regional firewood demand is estimated to be 1.5 million tones/year, only about 1/3 of this quantity can be supplied from current heathlands based on 10% yearly harvesting policy on rich heathlands. Also, regional timber demand is estimated as 170 thousand cubic meters.

In recent years, forest areas in the region were in decline due to ranging on heathlands, illegal fuel supply and conversion to arable lands. The national plan for forest improvement mainly consists of stages such as improvement of current grove areas and conversion of poor heath to rich heath and groves.

V.2.9.1 Forests Sector Description

GAPSIM forest model consists of two forest groups, grove and heath. Groves are identified with stock variables mature_grove, cleared_grove and young_grove acting as a material delay (see stock flow structure in Figure 5.25.). The stock variable mature_grove is converted to cleared_grove through mature grove harvesting and cleared_grove is converted to young grove through grove regeneration. Stock variable young_grove is maturated to mature_grove through young grove maturation flow. Mature grove harvesting rate is affected by regional timber availability and grove regeneration and maturation rates are affected by soil erosion.

Heathlands are also classified as mature_heath, cleared_heath and young_heath (see Figure 5.25.) where young_heath stock acts as a material delay and flow variables follow the same dynamics with that of grove.

But, there also exists poor_heath stock which is gradually converted to young grove and young heath through flows representing poor heath forestation and heath rehabilitation policies. These flows are affected by governmental policies.

GAPSIM forest model supplies timber (m^3/year) to the urban sector and firewood (tons/year) to the population and receives information from market sector about timber and energy availability from these sectors. Also, it receives information from populaton sector about population density on rainfed fields and supplies land for rainfed fields sector. Finally, it receives information about desired grove lands from governmental sector and receives information about current erosion level from erosion sector.

Stock variables in forests sector are

cleared_grove: cleared grove lands (ha).

young_grove: young grove lands (ha).

mature_grove: mature grove lands (ha).

cleared_heath: cleared heathlands (ha).

young_heath: young heathlands (ha).

mature_heath: mature heathlands (ha).

poor_heath: poor heathlands (ha).

Flow variables associated with these stock variables are

grove_regeneration: rate of regeneration of cleared_grove to young_grove (ha/year).

grove_maturing: rate of maturation of young_grove to mature_grove (ha/year).

grove_harvesting: rate of mature_grove harvesting (ha/year).

heath_regeneration: rate of cleared_heath regeneration to young_heath (ha/year).

heath_maturing: rate of young_heath maturation to mature_heath (ha/year).

heath_harvesting: rate of mature_heath harvesting (ha/year).

grove_planting: rate of conversion of poor_heath to young_grove (ha/year).

heath_planting: rate of conversion of poor_heath to young_heath (ha/year).

grove_to_rff: rate of conversion of cleared_grove to rainfed fields (ha/year).

heath_to_rff: rate of conversion of cleared_heath to rainfed fields (ha/year).

pheath_to_rff: rate of conversion of poor_heath to rainfed fields (ha/year).

Major converters with their units are

grove_land: cleared_grove+young_grove+mature_grove (ha).

grove_norm_regen_time: normal regeneration time for cleared grove, taken as 15 (years).

grove_norm_mat_time: normal regeneration time for young grove, taken as 30 (years).

erosion_mult_forest_dev: variable imported from erosion sector indicating effect of current erosion status of grove lands on grove development (unitless).

grove_regen_time: actual regeneration time for grove lands (years).

grove_mat_time: actual maturation time for grove lands (years).

grove_norm_harv_fract: normal harvesting fraction for mature grove, taken as 0.05 (1/years).

grove_unit_timber_yield: grove timber yield per hectare, taken as 1.1 (m^3/ha).

grove_timber_supply: quantity of timber supplied to the market (m^3/year).

per_timber_avail: perceived timber availability modeled as two years information delay of timber availability imported from market sector (unitless).

timber_avail_eff_harv: effect of timber availability on harvesting rate (1/year).

desired_grove_land: a variable imported from governmental sector, indicating desired quantity of grove lands for each year according to a fixed long term forestation program (ha) [Tarım Orman ve Köyişleri Bakanlığı Ulusal Ormancilik Master Planı, 1990 - 2009].

grove_planting_fract: a variable imported from governmental sector indicating rate of forestation according to the desired quantity of grove lands (1/year).

forest_fract_conv_fields: fractional conversion of forests to rainfed fields generated by population_density_rff imported from population sector (1/year).

The converters related with heathland stocks and flows are similar to the above converters relevant to grove lands. Timber supply and effect of timber availability on harvesting rate is replaced by firewood supply and effect of firewood availability on harvesting rate for heathlands.

In forests sector, as similar causal diagrams apply both to grove and heathlands, the major feedbacks only for groves are presented below (see Figure 5.24.). As mature_grove increases, increasing timber supply and increasing timber availability in the market leads to decreasing harvesting rates and increasing mature_grove and constitutes the first positive feedback loop. On the other hand, increasing mature_grove leads to increasing harvesting rates which leads to increasing mature_grove through a succession of causal links from cleared_grove to grove_maturing and constitutes the second positive feedback loop. But, grove planting rate controls this process with a negative feedback in between desired grove land and actual grove land. As grove land decreases, increasing

discrepancy between desired and actual grove land leads to increasing grove planting rate and increasing grove land. This negative feedback loop completes the causal loop diagram for grove lands in GAPSIM forest sector. In Figure 5.24., dashed circles represent those variables imported from other sectors and dashed arrows represent similar causal links which are already represented in the diagram. The cut arrow from timber availability to grove harvesting represents information delay.

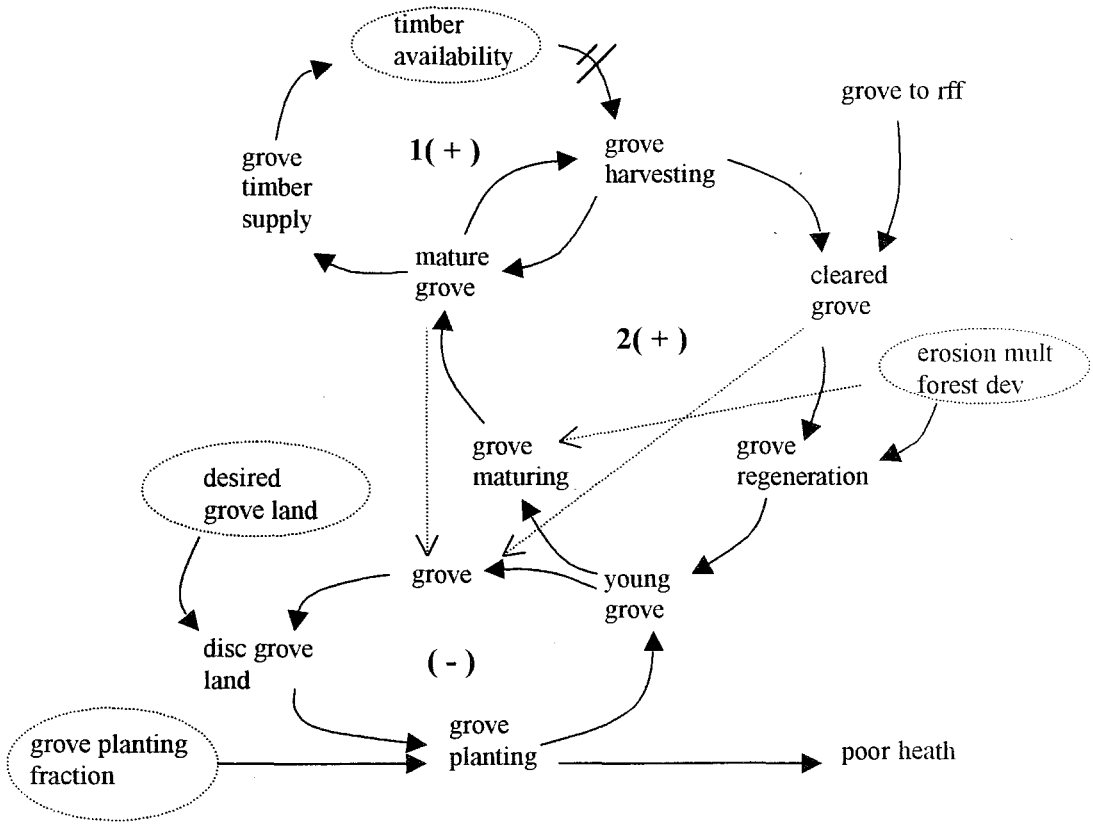


Figure 5.24. Causal loop diagram for GAPSIM forests sector.

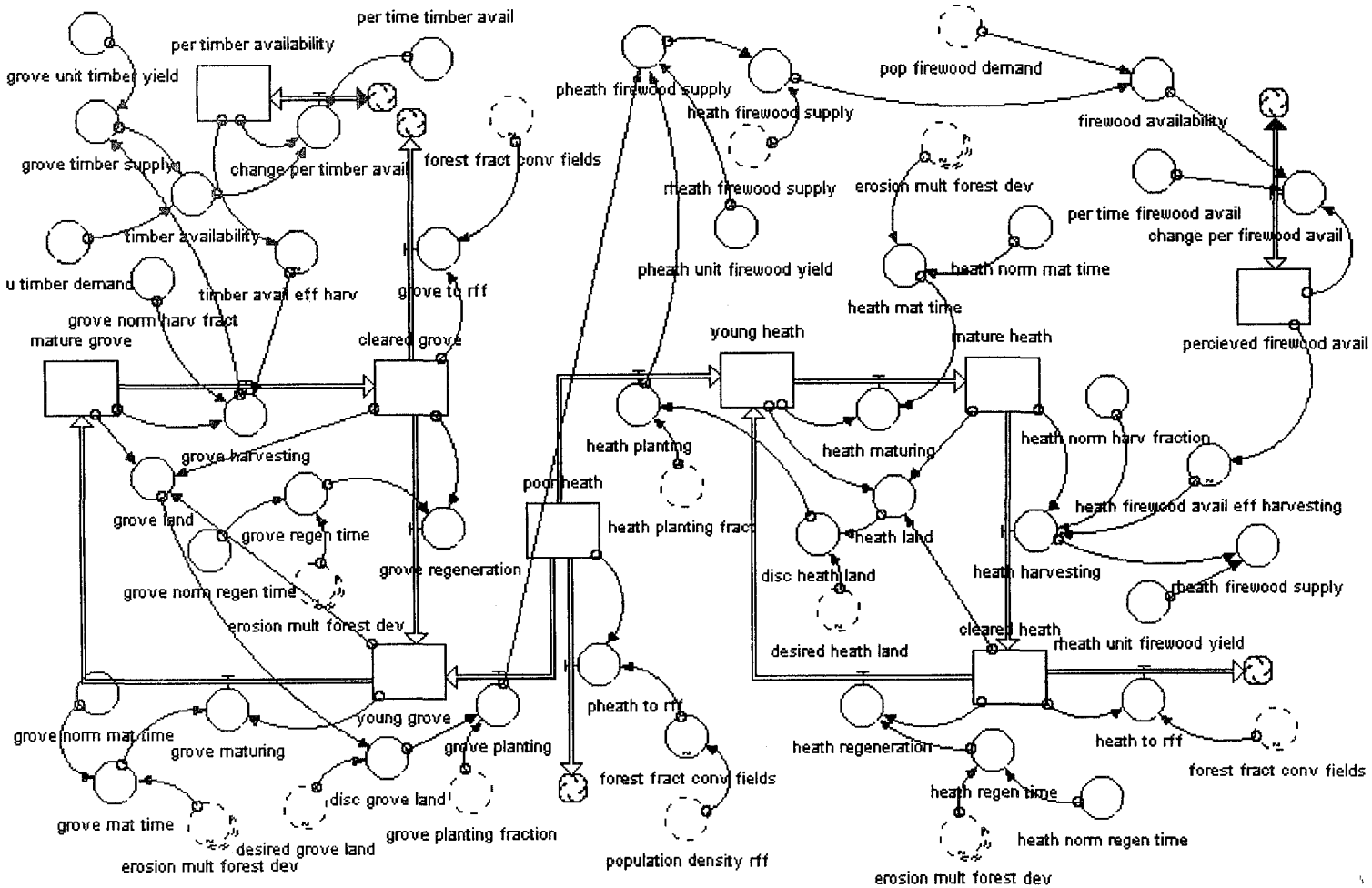


Figure 5.25. Stock-flow structure of GAPSIM forests sector.

Since same formulations apply both to groves and heathlands, here, formulations relevant to grove lands are given.

mature_grove(t)=mature_grove(t-1)+(grove_maturing-grove_harvesting)*dt (ha)

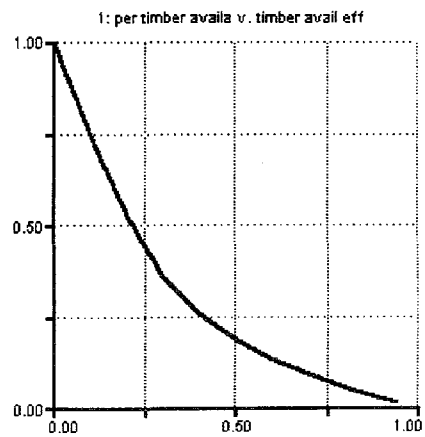
grove_maturing=young_grove(t-1)/grove_mat_time (ha/year)

grove_mat_time=grove_norm_mat_time/erosion_mult_forest_dev (year)

Functional form of erosion_mult_forest_dev is given in the relevant sector.

grove_harvesting=mature_grove(t-1)/(grove_norm_harv_fract+timber_avail_eff_harv) (ha/year)

The variable timber_availa_eff_harv is formulated as a function of timber availability according to the formulation presented below. Therefore, it is assumed that, as the percieved availability of timber decreases, the harvesting rate of mature groves increases:



The calculations related with cleared_grove lands are as follows:

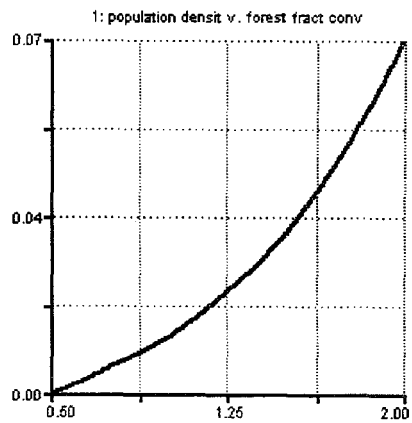
cleared_grove(t)=cleared_grove(t-1)+(grove_harvesting-grove_regeneration-grove_to_rff) *dt (ha)

grove_regeneration=cleared_grove(t-1)/grove_regen_time (ha/year)

grove_regen_time=grove_norm_regen_time/erosion_mult_forest_dev (year)

grove_to_rff=cleared_grove(t-1)/forest_fract_conv_fields (ha/year)

The variable forest_fract_conv_fields is formulated as a function of population density on rainfed fields as follows:



In GAPSIM forest model, poor heathlands are converted to young grove and young heathlands according to a governmental program. The flow variable representing grove planting on poor heathlands is formulated as follows:

grove_planting=disc_grove_land*grove_planting_fraction (ha/years)

disc_grove_land=grove_land-desired_grove_land (ha)

V.2.9.2. Forests Sector Simulation Runs

In GAPSIM forests sector, although initial values for total grove, total heath and poor heath lands are known to be 48000 ha, 280000 ha and 870000 ha respectively [4], initial values for stock variables are set assuming that the system should be in steady state under conditions ignoring (a) poor heath planting to grove and heathlands, (b) forest conversion to fields and (c) timber and firewood availability effects on harvesting rates. Then, initial values for cleared heath, young heath and mature heath stocks are 56000, 112000 and 120000 and initial values for cleared grove, young grove and mature grove are set as 13075, 23155 and 10770 respectively.

In Figure 5.26., a 10 percent planting fraction is applied and timber and firewood availability values are set to 0.5. Although there exists land conversion to rainfed fields, the control on timber and firewood availabilities and governmental action on poor heathlands planting to grove and heathlands constitute effective strategy. The control on

availabilities relax the first positive feedback loop in Figure 5.24. acting on harvesting rates. In the graphs in Figure 5.26., both mature grove (ha) and mature heath (ha) increase.

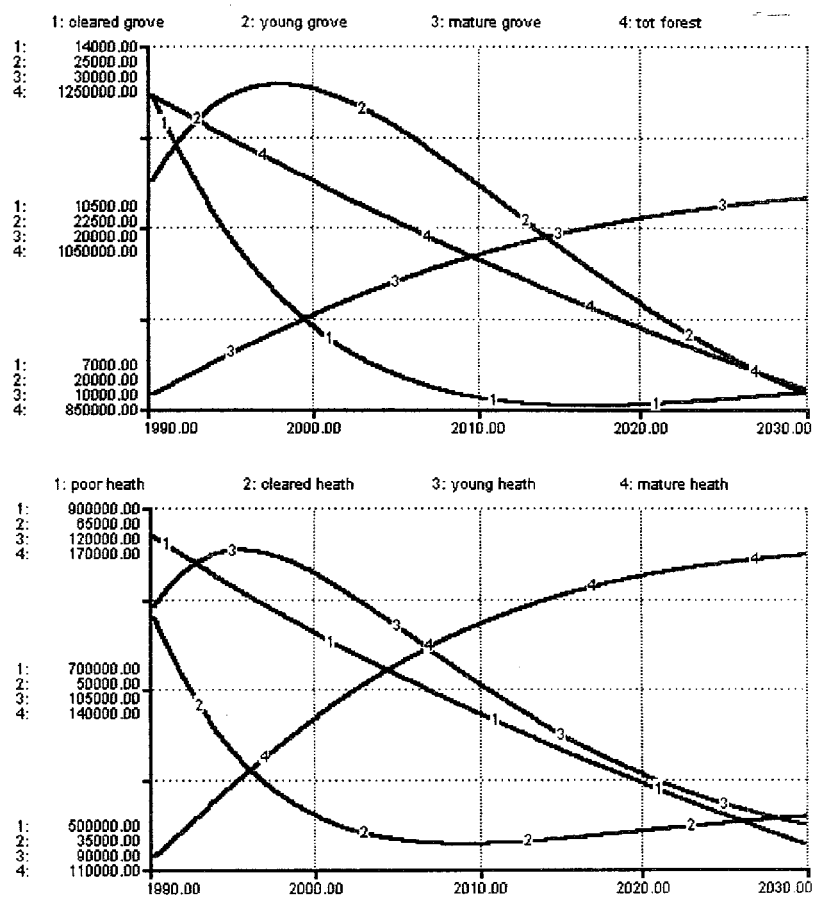


Figure 5.26. Sector isolated simulation of some control strategies for forests sector.

V.2.10. Erosion Sector

Soil erosion is a process where soil particles are detached from soil aggregates, transported by the energy of erosive agents such as wind and water and deposited to form new soils or fill lakes, reservoirs and oceans. The first and apparent problem associated with soil erosion is the loss of soil which affects production potential of the soil depending on its type and depth of soil. Together with the eroded soil, plant nutrients and organic matter are also lost which results in a decline in the productivity of soils [65].

The rate of soil erosion on a particular land is affected by rainfall characteristics, soil properties, slope characteristics (steepness and slope length) vegetative cover and management practices. A multiplicative equation called "universal soil loss equation" is used for estimation of erosion rates [66]. "Universal soil loss equation" is expressed as

$$A=R*K*LS*C*P \text{ (tons/ha/year)}$$

where A represents computed soil loss (tons/ha/year); R represents rainfall erosivity (MJ*mm/ha/hour/year); K represents soil erodibility (tons*ha*hour/ha/MJ/mm); LS represents topographic factor (dimensionless); C stands for cover management factor (dimensionless); and P for support practice factor (dimensionless). While the factors R, K and LS have certain values for a given site determining the basic erosion potential, last two factors C and P are readily changed by land use and management.

The rainfall erosivity factors for different locations in GAP region is summarized in Table 5.6. [67].

Table 5.6. Rainfall erosivity factors for different locations in GAP region.

Meteorological Station	R Factor
Ceylanpınar	19.540
Diyarbakır	27.261
Gaziantep	37.085
Siirt	51.594
Urfa	38.648

In GAP region, in plains, red - brown soils, on slopes, brown forest soils dominate and their K factors are calculated as between 0.08 - 0.23 and 0.04 - 0.22 respectively. But these values may increase up to 0.36 and 0.44 respectively. [68].

According to "Slope Map of Turkey" [69], GAP region consists of two main slope zones, where gentle slopes (0-6 %) and moderate slopes (6-20%) dominate. The LS factor for these slopes are calculated as 1.376 and 7.101 on the average respectively for length over 200 m and associated soil depths are accepted to be 1000 mm 600 mm on the average respectively [70].

Cover management factors for different vegetation are summarized in Table 5.7 [71].

Table 5.7. Cover management factors for different vegetation.

vegetative cover	cover management factor
bare soil	1.0
well stocked forests (unmanaged)	0.003 - 0.011
well stocked forests (managed)	0.001
medium stocked forests (unmanaged)	0.01 - 0.04
medium stocked forests (managed)	0.002 - 0.004
poorly stocked forests (unmanaged)	0.02 - 0.09
poorly stocked forests (managed)	0.003 - 0.009
pastures in good condition	0.001
range or poor pastures	0.05 - 0.1
cover plants of slow development	0.3 - 0.8
cover plants of fast development	0.01 - 0.1
row crops after fallow	1.0

According to these factors, forests provide the best cover factor while cover plants, i.e., croplands provide the worst.

Also, crop rotations, management variables including type of tillage, residue management, and time of soil protection by vegetation have impact on cover management factors, therefore on soil erosion rates on cultivated lands. As an illustration, the C factor for a 4 - year rotation of wheat - alfalfa - corn - corn with conventional tillage, average residue management and average yields is 0.119 while it is 0.48 for continous corn with conventional tillage [35]. More, according to soil erosion data for England, since considerably over average rainfall was received in December, January, and February and by this time winter cereals are well established so that they can act as a stabilizing factor, the majority of erosion occurred on land prepared for or cultivated with spring cereals [72]. Also, there is strong evidence that erosion on irrigated lands is more severe. [73]. The increase in erosion rates is ascribed to changing agricultural practices, notably the demise of traditional intercropping and its replacement by mechanized monoculture [74]. For

example, in US cotton belt, faster cultivation methods, a move towards cotton monoculture and a massive expansion of the cotton acreage caused a huge increase in soil erosion between 1870 and 1930 [75].

Values of P in literature, for different support practices depend on the slope steepness (Table 5.8) [76].

Table 5.8. Values for support practice factors in erosion control.

slope steepness (%)	contour tillage	contour strip cropping	terracing
1.1 - 2.0	0.60	0.30	0.30
2.1 - 7.0	0.50	0.25	0.25
7.1 - 12.0	0.60	0.30	0.30
12.1 - 18.0	0.80	0.40	0.40
18.1 - 24.0	0.90	0.45	0.45

V.2.10.1. Erosion Sector Description

GAPSIM erosion sector evaluates loss in soil depth on arable lands, rangelands and forests according to the formulation suggested by universal soil loss equation and parameters provided for GAP region. Then, calculates effect of soil erosion on farm yields and rangelands and forests regeneration. The model aggregates cover management factors for arable lands as rainfed fields, irrigated fields, rainfed wine-garden and irrigated wine-garden, for rangelands as rich rangelands, poor rangelands and bare soil and for forests as grove and heath. For computation of these variables, weighted averages of cover management factors for individual lands stocks are used. GAPSIM erosion sector creates erosion effect on regional yields and regeneration rates as a function of loss in soil depth.

As variables for arable lands, rangelands and forests are similar, only those related with rangelands are presented (see stock-flow structure in Figure 5.28.). The only stock variable is

soil_rangelands: soil quantity on unit rangeland (tons/ha).

Associated flow variable is

soil_loss_rangelands: soil lost from rangelands because of water erosion (tons/ha/year).

Converters are

rainfall_erosivity_range_forest: rainfall erosivity for rangelands and forests corresponding to R in literature (MJ.mm.ha-1.h-1.yr-1).

soil_erodibility_rangelands: soil erodibility factor for rangelands, corresponding to K in literature (t.ha.h.ha-1.MJ-1.mm-1).

topographic_factor_rane_forest: topographic factor for rangelands and forest, corresponding to LS in literature (unitless).

support_practice_rangelands: support practice factor for rangelands, corresponding to P in literature (unitless).

cover_man_rangelands: cover management factor for rangelands, C in literature (unitless)

soil_density: density of soil set as 2.65 (tons/ha).

norm_soil_depth_rangelands: normal soil depth for rangelands, set as 600 (mm).

soil_depth_rangelands: soil depth on rangelands calculated as a function of soil_rangelands and soil_density (mm).

remain_soil_ratio_rangelands: remaining soil ratio on rangelands calculated as ratio of soil_depth_rangelands to norm_soil_depth_rangelands (unitless).

eros_mult_range_regen: effect of soil_loss_ratio_rangelands on range regeneration rates (unitless).

eros_eff_cover_rangelands: effect of soil_loss_ratio_rangelands on cover management factor (unitless).

In GAPSIM erosion sector, a simple feedback structure consisting of two positive feedback loops act on rate of soil loss. The feedback loops are explained on rangelands in Figure 5.27. First, as soil on rangelands, then, soil depth on rangelands decrease, cover management factor for rangelands decrease, further increasing soil loss on rangelands and then soil on rangelands. This feedback loop is based on an assumption which is ignored in the formulation of universal soil loss equation that, cover management factors should

increase as quantity of soil supporting vegetative cover decreases [77]. The second positive feedback loop is related with the integration of erosion sector to the regional model. As remaining soil on rangelands decrease, poor range improvement rate decreases. This process leads to a relative decrease in quantity of rich rangelands among total rangelands. Then, cover management factor for rangelands, calculated as a weighted average of cover management factors of individual rangeland stocks increase and accelerate soil loss on rangelands. In Figure 5.27., variables enclosed with circles belong to rangelands and livestock sector.

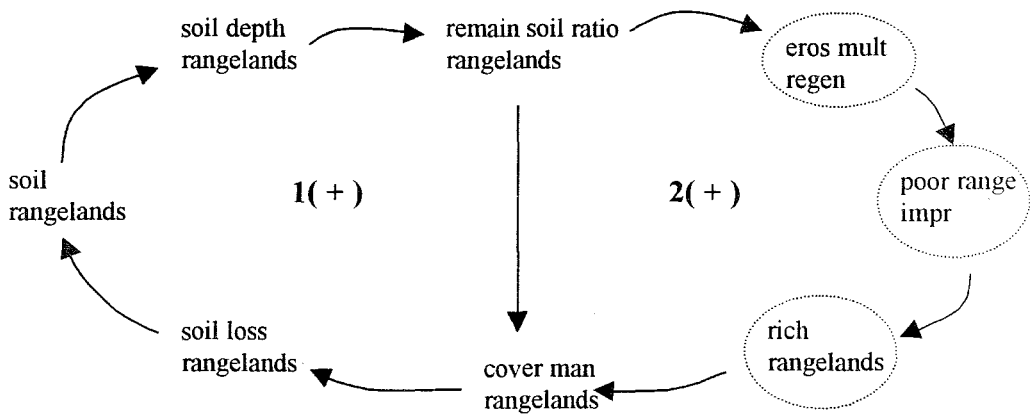


Figure 5.27. Causal loop diagram for GAPSIM erosion sector.

In Figure 5.28., the section of stock-flow structure of GAPSIM erosion sector related with rangelands is presented.

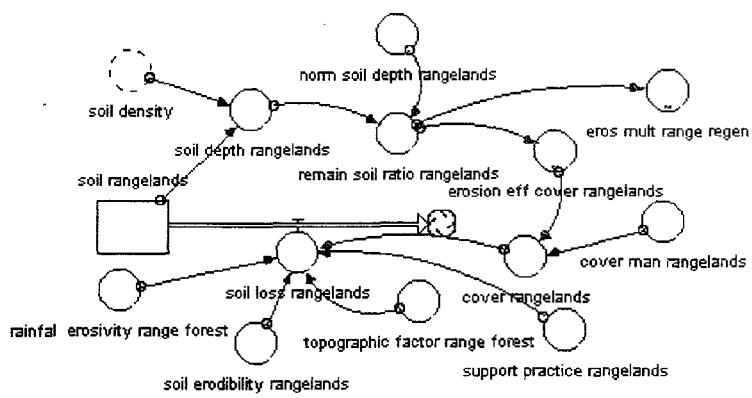
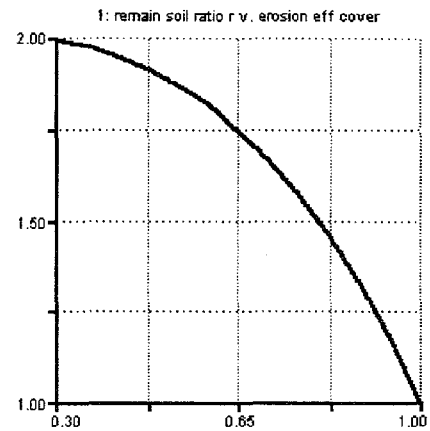


Figure 5.28. Stock-flow structure of GAPSIM erosion sector.

In erosion sector, soil loss is calculated as it is suggested by the universal soil loss equation.

soil_loss_rangelands=rainfal__erosivity_range_forest*soil_erodibility_rangelands*topographic_factor_range_forest*cover_rangelands*support_practice_rangelands (ton/ha/year).

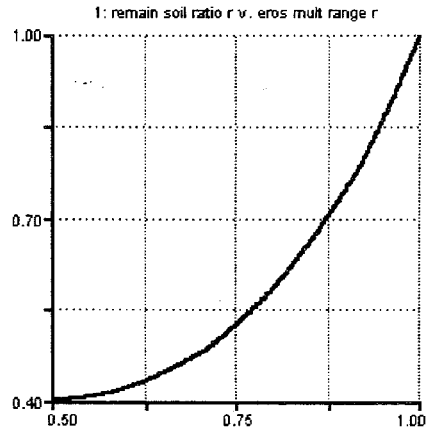
The variable cover_rangelands is calculated as a multiplication of cover_man_rangelands and erosion_eff_cover_rangelands. The variable erosion_eff_cover_rangelands is formulated as a function of remaining soil ratio according to the following graphical function:



Therefore, it is assumed that, cover management factor may increase by a factor up to two, if about 70 percent of original soil depth is lost because of water erosion. The variable remain_soil_ratio rangelands is measured as

remain_soil_ratio_rangelands=soil_depth_rangelands/norm_soil_depth_rangelands (unitless).

The variable eros_mult_range_regen is formulated as a function of remain_soil_ratio_rangelands according to the relationship given below:



This formulations for eros_mult_forest_dev and eros_mult_base_yield are similar to the formulation of eros_mult_range_regen. Summarization of data from many studies showed that 2.5 cm of soil loss reduced wheat yield 5.3 %, corn 6.3%, grain sorghum 5.7 % [35].

V.2.10.2. Erosion Sector Simulation Runs

In Figure 5.29., sector isolated runs for erosion multiplier on yields and regeneration rates (all unitless) demonstrated. For graph (a), lines one, two, three and four stand for rainfed fields, rainfed wine-garden, irrigated fields and irrigated wine-garden. The behavior on (a) show that, although the support practice factor is set to its maximum value (1), erosion on GAP arable lands is not a severe problem as the average slope is mild (between 0-6%) and rainfall erosivity is low (40).

However, on graph (b), The behavior of erosion multiplier on heathlands and rangelands show that erosion is a moderate problem on these slopes since both topographic factor and rainfall erosivity increase for these lands. Therefore, erosion control practices are essential.

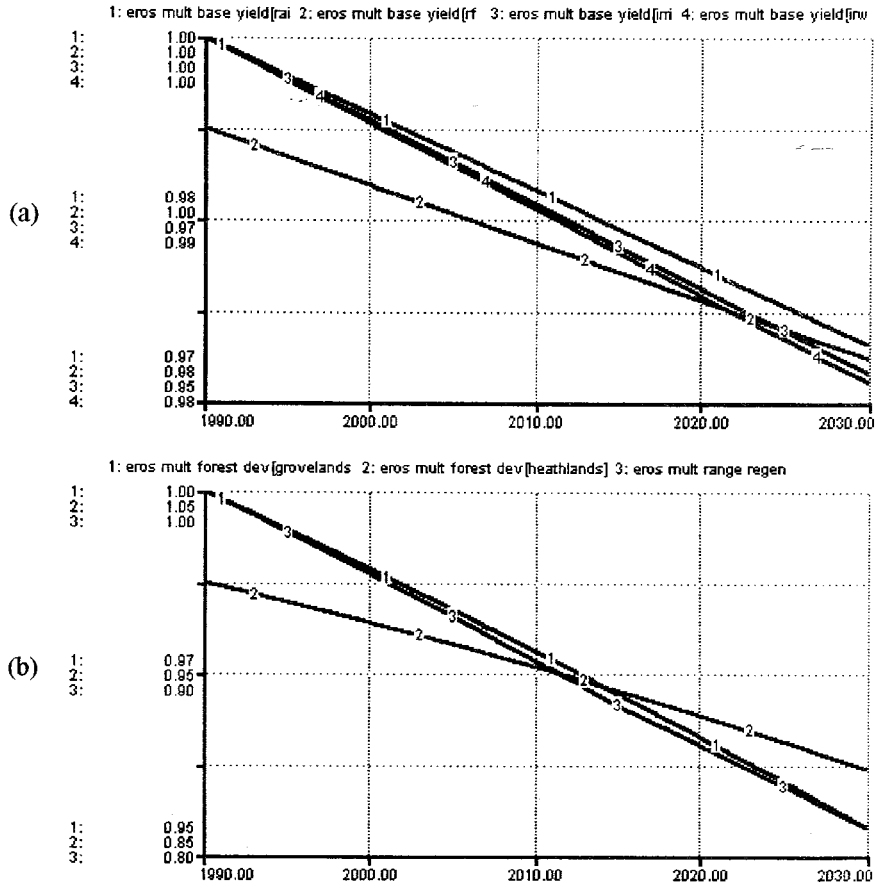


Figure 5.29. Sector isolated runs for GAPSIM erosion sector.

V.2.11. Urban Sector

Urban GAP consists of nine city centers, Adıyaman, Batman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa, Şırnak and their towns. The businesses in these urban sites are classified according to ISIC Rev. 2 (International Standard Industrial Classification of All Economic Activities, Second Revision) by State Institute of Statistics Prime Ministry Republic of Turkey (SIS). According to this classification, agriculture; mining; manufacturing; electricity, gas and water; construction; commerce; communication, transportation; service; and public works exhausts all economic activities. In "The 1992 General Census of Industry and Business Establishments", the quantity of business structures, their respective employee (jobs), raw material requirements (TL/year), water requirements (m3/year), energy requirements (kWh/year) and amount of production (TL/year) are tabulated with respect to different business sizes [78].

In GAP, those manufacturing industries processing agricultural products (31,32,33,34 in Table 5.9) such as manufacture of food and beverages, textile wearing apparel and leather industries, manufacture of wood and wood products and manufacture of paper and paper products comprise the major group. Then comes the second group of industries manufacturing fabricated metal products, machinery and equipment, transport equipment, professional and scientific and measuring and controlling equipment mainly for use in production activities and as consumption goods (38 in Table 5.9). Last comes those manufacturing industries producing mainly agricultural production factors such as fertilizers and pesticides and other production factors for manufacturing industry (35,36,37,39 in Table 5.9). Therefore, initially, basic input for GAP manufacturing industry is agricultural products [79,80].

Table 5.9. Distribution of manufacturing industry in GAP region, 1992. Summarized from the "1992 General Census for Industry and Business Establishments".

ISIC Rev. 2 Class No	activity	large sized manufacturing establishments	% large sized	small sized manufacturing establishments	% small sized
31	food and beverages	68	27	2212	20
32	textile and wearing	72	28	3590	32
33	wood and wood products	7	3	1740	16
34	paper and paper products	8	3	125	1
35	chemicals and chemical products	38	15	611	5
36	non metallic mineral products	9	4	275	2
37	basic metal industry	8	3	102	1
38	fabricated metal products	43	17	2336	21
39	other manufacturing industries	-	-	175	2
	regional total	253	100	11166	100

The employment structure of urban GAP according to the activities classified by ISIC Rev. 2 is tabulated on Table 5.10. [81]. According to this data of 1985, employment in GAP region is at very low levels and public jobs constitute the major employment area. Manufacturing, commerce and construction are the other major activities. Though this data of year 1985 is rather old, it can more or less be taken as initial conditions for simulation runs starting at 1990 assuming that there is not significant changes between 1985 and 1990.

Table 5.10. Urban employment in GAP region with respect to different economic activities.

ISIC Rev. 2 Class No	activity	employment
2	mining	3079
3	manufacturing	76437
4	electricity, gas and water	1221
5	construction	49322
6	commerce	61802
7	transportation and telecommunication	37861
8	service	56675
9	public	154771
total		441169

According to GAP Master Plan, the idea is to improve GAP business structures and initiate urbanization by eliminating current constraints on this process. These constraints are insufficient capital accumulation, small regional market, insufficient water and energy supply and weak telecommunication and transportation facilities [9]. Therefore, the increasing agricultural production together with improved infrastructure will initiate an industrial growth which should create synergistic effects on urban development.

V.2.11.1. Urban Sector Description

GAPSIM urban sector is an aggregation of all urban sites in GAP taken as a system of interacting industries, housing and urban population. GAPSIM urban model consists of several industry and business structures which are aggregations of certain economic activities listed according to ISIC Rev. 2 classification. Each industry and business structure in GAPSIM urban model creates requirements for labor (creates jobs), land, energy and water. Each industry structure creates its own products for consumption of either other industry and business structures or population and creates demand for some other industries products.

The manufacturing businesses are aggregated under four different groups emphasizing their different input and output relationships within the regional economy. These are industry structures processing agricultural products and producing consumption goods (agroout_ind_struct) which aggregates activities 31 to 34 in Table 5.9; industry

structures producing agricultural inputs (agrooin_ind_struct); industry structures producing consumer goods (consumers_ind_struct); and industry structures producing production factors (prod_ind_struct) all aggregating different subactivities of activities 35 to 38.

Also, activities in Table 5.10. are aggregated under different business structures and jobs. No. 8. is aggregated under service businesses (service_busin_struct), no. 6. under commercial businesses (commerc_busin_struct), no. 5. under construction, no. 4. and no. 7. under total structures and no. 9. is aggregated under public jobs.

Each business structure and housings in the model has certain initiation and demolition rates determined by several model assumptions. All initiations in the model are derived according to a normal initiation rate which is in acceptable limits for GAP region and this rate is modified according to the land, labor and demand constraints [82]. Hence, all structures in GAPSIM urban model compete for land and labor resources where land represents the aggregation of all available urban lands and labor represents the aggregation of urban labor according to a fixed labor fraction. The demolition rates are determined according to a normal lifetime representing average aging and obsolescence for business structures and housings.

Stock variables in GAPSIM urban sector are

agroout_ind_struct: those industry structures producing consumption goods, whose raw materials are either agricultural products or processed agricultural products (agroout industry unit). It also creates demand for its own products, producers industry products, service business and timber. Initial value is estimated as 2350 middle industry units [4,79,80].

agroin_ind_struct: those industry structures producing agricultural production factors whose raw material supply is out of question in the model (agroin industry unit). It creates demand for producers industry products and service business. Initial value is estimated as 850 middle industry units according to the references used for agroout_ind_struct.

consumers_ind_struct: those industry structures producing consumer goods whose raw material supply is out of question in the model (consumers industry structure). It creates

demand for producers industry products and service business. Initial value is estimated as 720 middle industry units.

prod_ind_struct: those industry structures producing production factors for all industry structures whose raw material supply is out of question in the model (producers industry structure). It creates self demand for its own products and service business. Initial value is estimated as 710 middle industry units.

service_busin_struct: those structures which produce service for population and industries (service business unit). It creates demand for agroout and consumers industry products. Initial value is estimated as 15000 [78].

commerc_struct: those structures engaged in commercial activities (commerce unit). Their material input and output relations are ignored in the model (commerce unit). They create demand for consumers industry and service business products. Initial value is estimated as 40000 units [78].

houses: those structures providing housing for population (house units). Initial value is estimated as 400000 assuming that housing availability is 0.85.

construction: ongoing constructions creating labor, energy and water requirement and demand for producers industry goods (construction units).

urban_land: land available for industry, business and housing structures (ha). Initial value is 11000 ha [83].

public_jobs: jobs created governmentally according to a certain employment policy (jobs). Initial value is 155000 jobs [4]

Many of the flow variables in GAPSIM urban model represents initiation and depreciation of business structures and are similar to each other. Here, among flow variables related with industry units, only those associated with agroout_ind_struct are presented.

agroout_ind_initiation: initiation rate of agroout industry structures (agroout industry unit/year).

agroout_ind_demolition: demolition rate of agroout industry structures (agroout industry unit/year).

housing_construction: construction rate of houses (house unit/year).

housing_demolition: demolition rate of houses (house unit/year).

construction_starts: starting rate of constructions (construction unit/year).

construction_ends: ending rate of constructions (construction unit/year).

increase_urban_land: increase in urban land (ha/year).

change_public_jobs: change in public jobs (jobs/year).

Major converters in urban model are

agroout_ind_normal_init: normal growth fraction for agroout industry structures taken as 0.075 (1/year).

total_structures: dummy structures generated as a summation of business structures and housings according to fixed coefficients, representing municipal development creating jobs and consuming land, water and energy (unit structures).

urban_land_occup: total land occupied by business structures, houses and total structures (ha). Land occupied by individual urban structures are estimated from "GAP Provincial Statistics" [84].

fract_urban_land_occup: fraction of urban land occupied, calculated as ratio of urban_land_occup to urban_land (unitless).

land_eff_init: effect of fract_urban_land_occup on business structure initiation and housing construction rates (unitless).

pressure_new_land: pressure for new land created by fract_urban_land_occup (1/year).

urban_land_prior_coeff: an experimental coefficient between 1 and 4, indicating urban priority relative to agriculture in land use (unitless). 1 indicates highest urban priority.

urban_jobs: total urban jobs, calculated as summation of jobs created by businesses, construction, mining, municipal and public activities (jobs). Jobs created by individual businesses are estimated from "The 1992 General Census of Industry and Business Establishments" and "The Economic and Social Characteristics of Population, 1985". [79,80,81].

desired_urban_job_avail: a policy variable imported from government sector indicating desired employment (unitless). This variable is initially set to 0.65.

desired_to_urban_job_avail_ratio: ratio of desired_urban_job_avail to urban_job_avail (unitless).

fract_change_public_jobs: fractional change in public_jobs created by desired_urban_job_ratio (1/year).

urban_labor_fract: fraction of total urban population either working or looking for a job (man/capita), estimated as 0.35 [84].

urban_labor: urban population either working or looking for a job (man).

urban_job_avail: urban job availability (unitless), ratio of urban_jobs to urban_labor.

job_avail eff_init: effect of urban_job_avail on business initiation rates (unitless).

job_avail_eff_per_cap_dem: effect of urban_job_avail on per capita demand of urban population (unitless).

agroout_ind_product_norm_dem_per_uhous: normal demand for agroout industry products per urban household estimated from "1994 Household Consumption Expenses Statistics " and discounted to September 1997 prices according to "State Institute of Statistics Price Index (TL/household/year) [85].

agroout_ind_product_dem_per_hous: demand for agroout industry products per household calculated by multiplying agroout_ind_product_norm_dem_per_uhous with job_avail_eff_per_cap_dem (TL/household/year).

upop_dem_agroout_ind_product: urban population demand for agroout industry products calculated by multiplying agroout_ind_product_dem_per_uhous with urban_households (TL/year).

agroout_ind_unit_product: unit agroout industry production (TL/agroout industry unit/year). This parameter is summarized from "General Census of Industry and Business Establishments, 1992" [79,80] and discounted for September 1997 prices according to "State Institute of Statistics" general price index.

agroout_ind_product: total yearly production of agroout industry structures (TL/year).

exregional_dem_agroout_ind_prod: exregional demand for agroout industry products (TL/year).

agroout_ind_product_dem: demand for agroout industry products, which consists of population demand, agroout industry self demand, service business demand and exregional demand for agroout industry products (TL/year).

agroout_ind_product_avail: availability of agroout industry products in urban sector measured as the ratio of agroout_ind_product to agroout_ind_product_dem (unitless).

product_eff_agrrout_ind_dem: effect of agroout_ind_product_avail on agroout industry demolition rate {unitless}.

Variables concerning production and demand for other business structures are estimated from "Statistics for Commerce and "Statistics for Service" [86,87].

agroout_ind_unit_rawmat_dem: unit agroout industry demand for agricultural commodities in the market sector (TL/agroout industry unit/year). The raw material requirement value summarized from statistics is shared between parameters agroout_ind_unit_rawmat_dem, agroout_ind_unit_self_demand, agrrout_ind_unit_prod_ind_dem according to 60:20:20 ratio respectively [79,80]

agroout_ind_rawmat_dem: agroout industry total demand for agricultural commodities (TL/year).

agroout_ind_rawmat_supply: a variable imported from market sector representing total supply of agricultural commodities for industrial processing (TL/year).

agroout_ind_rawmat_avail: availability of agricultural commodities for agroout_ind_struct measured as the ratio of agroout_ind_rawmat_supply to agroout_ind_rawmat_avail (unitless).

rawmat_eff_agroout_ind_init: effect of agroout_ind_rawmat_avail on agroout industry initiation (unitless).

agroout_ind_init_rate: initiation rate for agroout_ind_struct which consists of multiplication of factors agroout_ind_normal_init, land_eff_init, job_avail_eff_init, product_eff_agrrout_ind_init and rawmat_eff_agroout_ind_init (1/year).

agroout_ind_norm_demolit: agroout industry normal demolition rate due to aging and obsolescence (years), taken as 0.05.

agroout_ind_unit_timber_dem: unit agroout industry timber demand (m3/agroout industry unit/year). [4].

agroout_ind_timber_dem: variable exported to forests sector indicating agroout industry timber demand (m3/year).

Converters relevant to initiation and demolition rates of other business structures are similar to those for agroout_ind_struct but raw material requirement is concerned only for agroout_ind_struct.

net_ind_init: change in number of industry structures measured as their initiation minus demolition (industry unit/year).

normal_net_ind_init: normal change in number of industry structures taken as 100 (industry unit/year).

ind_init_ratio: ratio of change_ind_struct to nominal_change_ind_struct (unitless)

ind_init_eff_comm_busin_init: effect created by ind_init_ratio on commercial business initiation (unitless)

upop_household_size: average household size for urban population set to 6 (capita). This value is estimated from "GAP Provincial Statistics, 1950 - 1996" and "1994 Household Consumption Expences Statistics" [84,85].

urban_households: number of urban households (households).

housing_availability: availability of houses to households measured as the ratio of houses to households (unitless).

housing_avail_eff_const: effect of housing availability on housing construction (unitless).

busin_initiation: total initiation rate for commercial and service businesses (business unit/year).

busin_const_coeff: construction unit corresponding to unit business initiation set as 2 (unit construction/business unit).

ind_construction: total construction rate of industries (industry unit/year).

ind_const_coeff: construction unit corresponding to unit industry initiation set as 10 (unit construction/industry unit).

housing_construction: housing construction (house unit/year)

housing_const_coeff: construction unit corresponding to unit house construction set as 1 (unit construction/house unit).

urban_water_req: total urban water requirement calculated by summing up water requirements of businesses, housings, construction and municipal activities (m^3/year). While estimating water requirements for individual urban structures, several documents of "İstanbul Municipality Water Works" are used [88].

urban_energy_req: total urban energy requirement calculated by summing up energy requirements of businesses, housings, construction and municipal activities (kWh/year). Energy requirement for individual structures are estimated from several documents [79,80,89].

GAPSIM urban sector is a system of interacting businesses, housings and population where growth processes are controlled through several negative feedbacks representing land, labor, rawmaterial and demand constraints (see causal loop diagram in Figure 5.30). Though causal structure for the urban model is more complex, in the causal loop diagram, feedbacks relevant to agroout industry structures are given. This diagram also includes feedbacks related with urban land and labor constraints. Feedback loops concerning other urban structures are similar to those for agroout industry structures and while these structures stimulate each others growth by creating demand for their products, they also compete with each other for land and labor. In Figure 5.30., variables enclosed with dashed circles represents variables imported from other sectors.

In the first feedback loop, increasing industry structures increase jobs which creates an increase in urban job availability. This means higher employment and lower initiation for industry structures. This completes the first feedback loop. Also, any increase in industry structures increases urban land actively occupied which increases fraction of urban land occupied and again decreases industry initiation rate. This is the second feedback loop in the diagram. Third, any increase in industry structures creates an increase in rawmaterial demand which is supplied by agriculture through market sector. Increasing rawmaterial demand means decreasing availability and decreasing initiation rate. Fourth feedback loop is about demand for industry products. Increasing industry structures increase industry products demanded by other business structures and by population and this increases the availability of these goods which in turn increases the demolition rate of

industries. Increasing demolition rates means decreasing industry structures which completes the fourth negative feedback loop.

In the diagram the fifth and sixth loops represents processes affecting urban jobs and urban land respectively. The model compares urban job availability with a desired value for job availability which is a fixed policy variable imported from government sector. If urban job availability is too low when compared to the desired value, public jobs, hence urban jobs are increased. This is the fifth feedback loop. Last comes the sixth loop. When fraction of urban land occupied increases this creates an increase in urban land and fraction of urban land occupied decreases.

In the causal loop diagram, urban population creating both labor and demand for industry products, urban energy and water requirements created by urban structures and timber requirement created by agroout industry structures are also represented.

In Figure 5.31., a simplified stock-flow structure for GAPSIM urban sector is presented.

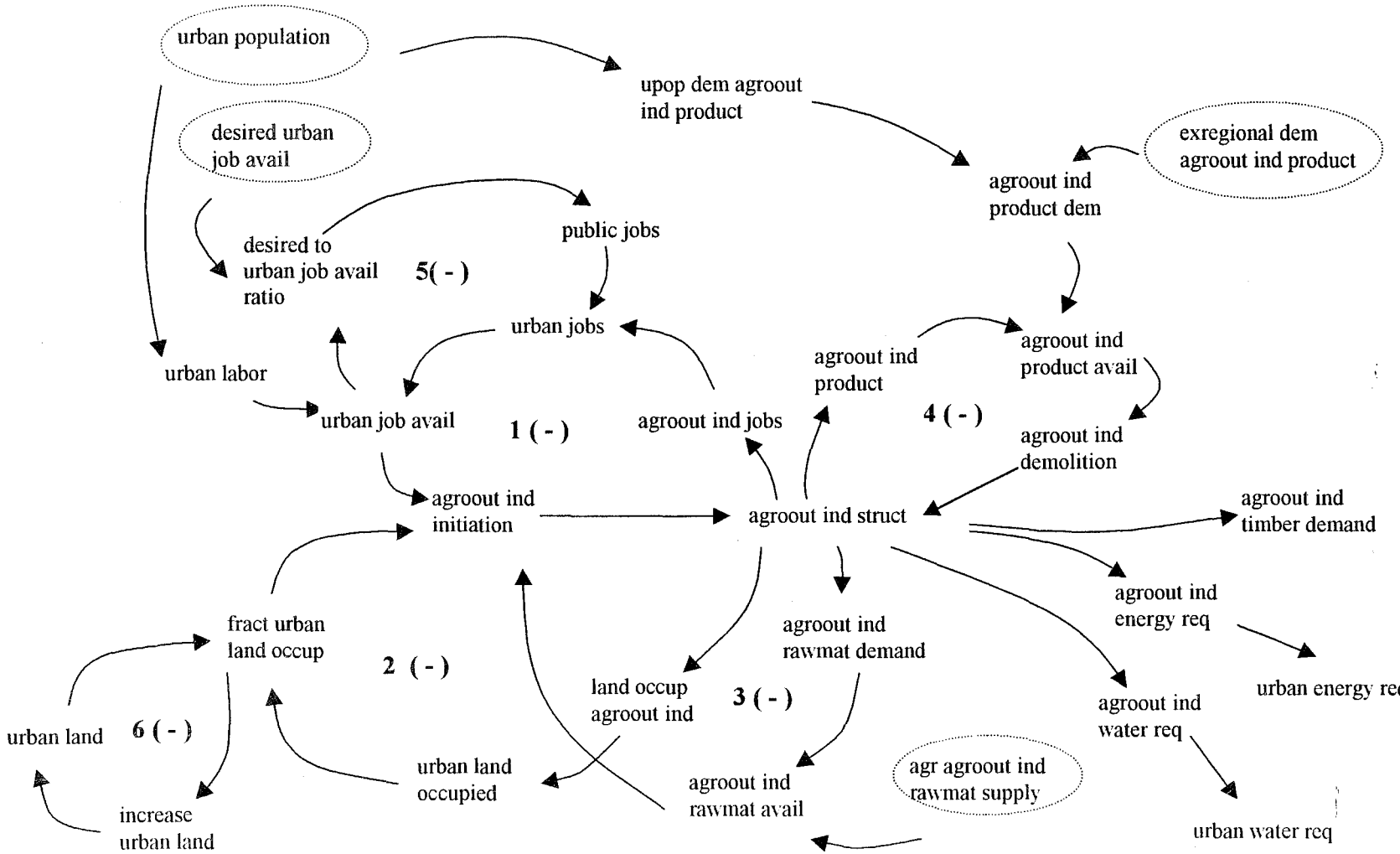


Figure 5.30. Causal loop diagram for GAPSIM urban sector.

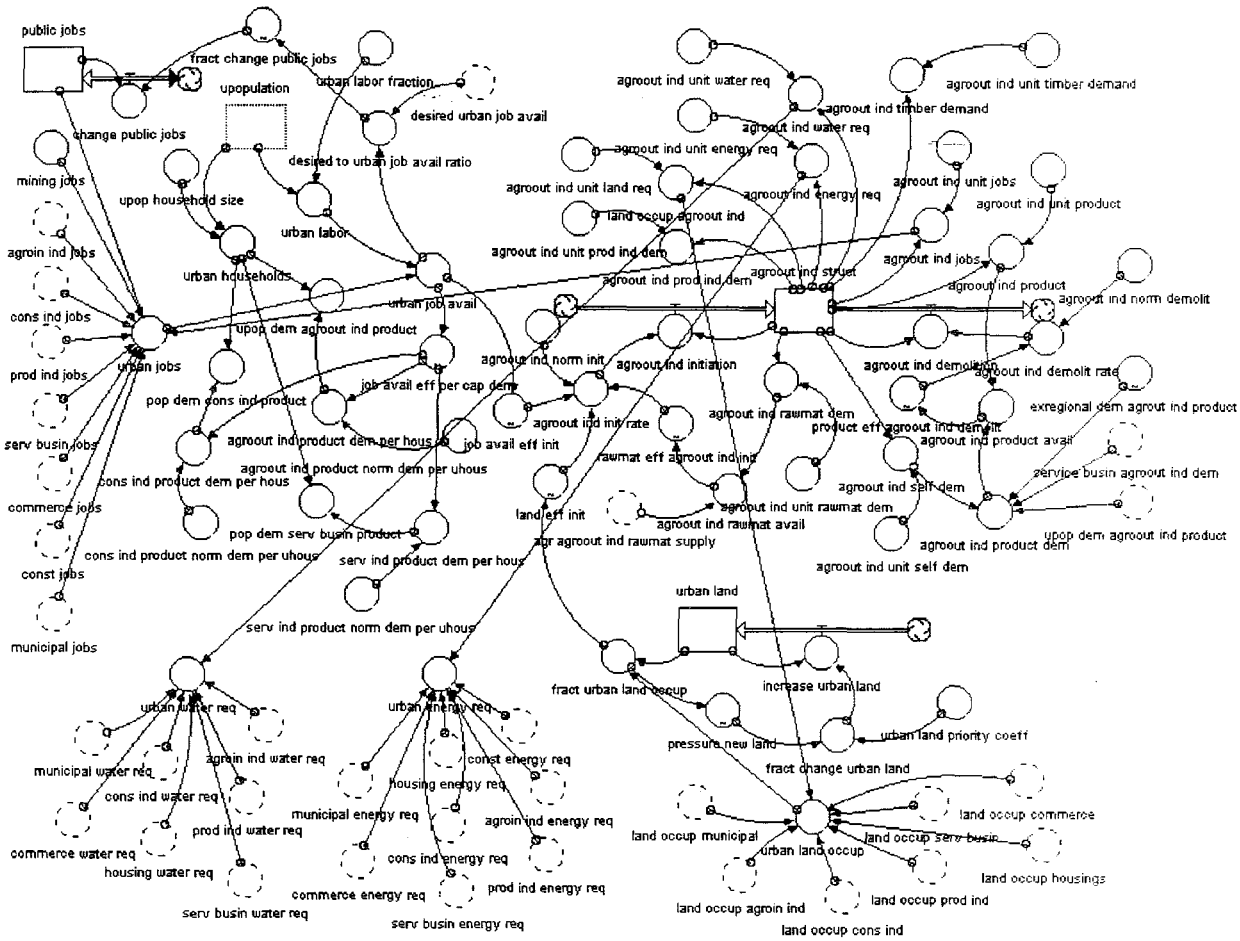


Figure 5.31. Simplified stock-flow structure of GAPSIM urban sector.

Business structures in GAPSIM urban model increase with business initiation and decrease with business demolition rates. Since formulations for different urban structures are similar, here, formulations related with agroout_ind_struct are given. The value of stock variable agroout_ind_struct increases with flow variable agroout_ind_initiation and decrease with flow variable agroout_ind_demolition.

agroout_ind_struct(t+1)=agroout_ind_struct(t)+(agroout_ind_initiation-agroout_ind_demolition)*dt (industry units)

agroout_ind_initiation=agroout_ind_struct(t) *agroout_ind_init_rate (industry/year)

agroout_ind_init_rate=agroout_ind_norm_init*job_avail_eff_init*land_eff_init*rawmat_eff_agroout_ind_init (1/year)

In this formulation, agroout_ind_norm_init is a constant which is accepted to be 0.075, i.e. under initial conditions for land and labor constraint and when rawmaterial availability is 1, every year, new agroout_ind_struct are initiated by 7.5 % of existing agroout_ind_struct. The variable job_avail_eff_init is formulated as a function of urban_job_avail where

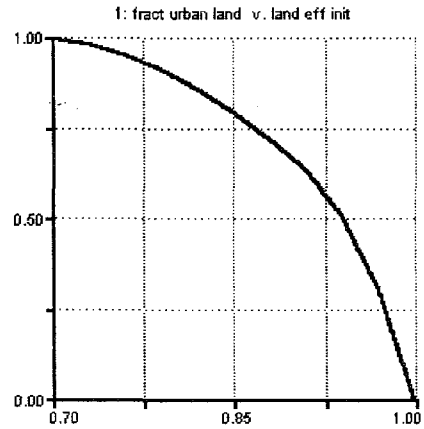
urban_job_avail=urban_jobs/urban_labor (unitless)

When urban_job_avail is low, there is underemployment, therefore, demand for new jobs is high. But when this value increases, either labor costs increase or new created jobs become idle which create a factor inhibiting growth of business structures. This fact is formulated according to the functional form given below:

Second factor affecting industry initiation rates is land_eff_init which is a function of fract_urban_land_occup where

fract_urban_land_occup=urban_land_occup/urban_land (unitless)

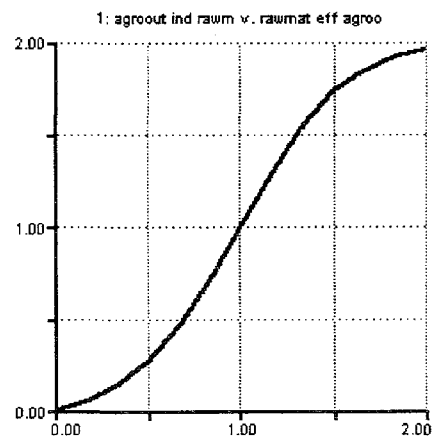
The variable land_eff_init represents the effects of land availability on initiation rates. The development of infrastructure, diversity of choice and land prices has no input to this multiplier but they are all implicit in the functional relationship below: [82].



The third effect on agroout_ind_initiation is rawmat_eff_agroout_ind_init which is a function of agroout_ind_rawmat_avail where

agroout_ind_rawmat_avail=agr_agroout_ind_rawmat_supply/agroout_ind_rawmat_dem (unitless)

The variable rawmat_eff_agroout_ind_init represents the effects of rawmaterial availability on initiation rate. High availability is an indicator for low rawmaterial costs where low availability indicates high costs or scarcity inhibiting industrial growth. These factors are implicit in the graphical function below:



Urban structures decrease through flow variables representing demolition rates. For example,

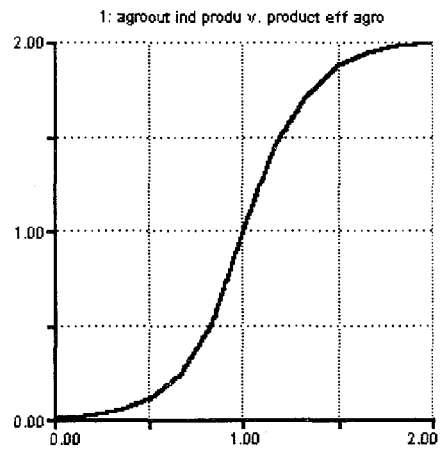
agroout_ind_demolition=agroout_ind_struct*agroout_ind_demolit_rate (industry/year) and

agroout_ind_demolit_rate=agroout_ind_norm_demolit*product_eff_agroout_ind_demolit (years)

The variable agroout_ind_norm_demolit represents normal demolition rate for agroout_ind_struct due to aging and obsolescence under normal conditions. This value is assumed to be 0.05 (1/year). The effect of availability of industry products on industry growth are represented by the variable product_eff_agroout_ind_dem acting on agroout_ind_norm_demolit. This effect is a function of agroout_ind_prod_avail.

agroout_ind_prod_avail=agroout_ind_product/agroout_ind_product_dem (unitless)

The variable product_eff_agroout_ind_dem increases average lifetime of industries if there exists demand for industry products and decrease their lifetime if there is less demand, i.e. there is overcapacity of industry structures. This relationship is represented by this graphical function:



In the model, public jobs increase according to a governmentally determined desired job availability criteria. When urban job availability is below desired level, public jobs increase according to this governmental policy.

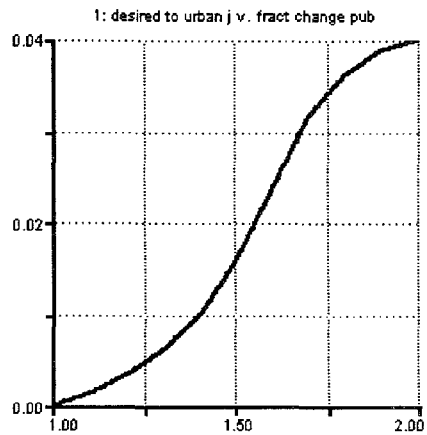
public_jobs(t+1)=public_jobs(t)+change_public_jobs*dt (jobs)

The flow change_public_jobs is formulated as a 3 years first order delay of a fractional change created by desired_to_urban_job_avail_ratio and public_jobs. This delay represents delay in governmental action.

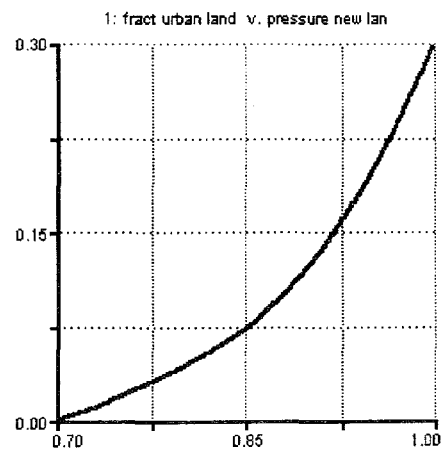
change_public_jobs=SMTH1(public_jobs*fract_change_public_jobs, 3) (jobs/year)

desired_to_urban_job_avail_ratio=desired_urban_job_avail/urban_job_avail (unitless)

As this ratio gets larger, the governmental need to create public jobs increase. The functional form for fract_change_public_jobs is presented below:



Urban land in GAPSIM increases due to pressures resulting from urban growth. As the density of urban structures increase and begin to exert pressure on urban growth, new urban sites are created in order to relax these pressures. This pressure is formulated as a function of fract_urban_land_occup. As more land is occupied, pressure for new lands increase:



But, priority of agriculture plays an imported role in growth of urban land. When there is strict regulations for agricultural land use or when agricultural land itself has high rents, growth of urban land may be prevented in spite of those internal pressures. Therefore, fractional change in urban land is a function of both internal pressures for new land and urban land priority relative to agricultural land use.

fract_change_urban_land=pressure_new_land/urban_land_priority_coeff (1/year)

Then, actual increase in urban land is formulated according to the formulation

urban_land(t+1)=urban_land(t)+increase_urban_land*dt (ha)

increase_urban_land=urban_land(t)*urban_land_change_fract (ha/year)

V.2.11.2. Urban Sector Simulation Runs

In Figure 5.32., isolated run for GAPSIM urban sector are demonstrated. In isolated run, agroout industry raw materials supply and agroin industry products demand are constant. Under these conditions, GAP urban system go to stagnation after a mild increase in business structures and housings and urban jobs (jobs), land (ha), energy (kWh/year) and water (m^3/year) requirements. This increase is mainly due to on going urban population increase.

In Figure 5.33., the response of GAP urban system to agricultural development is demonstrated. In this run, rawmaterials supply for agroout_ind_struct and product demand for agroin_ind_struct increase. The stimulation of initiation rates of two industry structures related with agricultural production create synergistic effects on initiation rates of other industries according to the model structure and lead to increasing urban jobs, land, energy and water requirements.

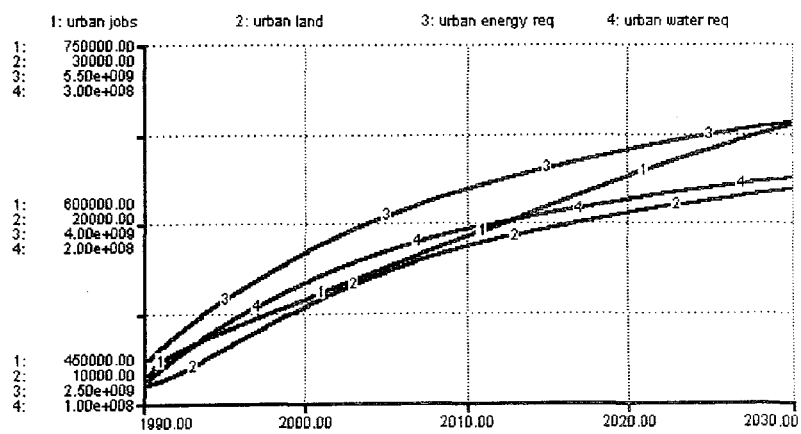


Figure 5.32. Urban jobs, land, energy and water requirement in urban sector isolated run.

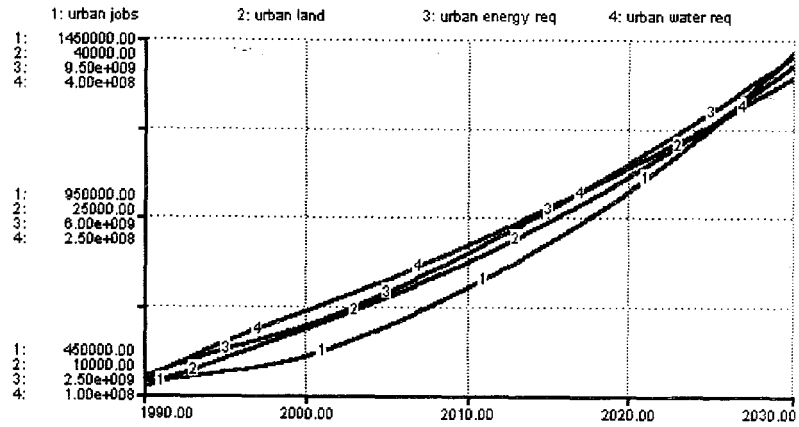


Figure 5.33. The response of GAP urban system to agricultural development.

V.2.12. Population Sector

The data concerning size of population in GAP cities and towns, size of population in subsettlements and villages, net regional migration rate and rate of population increase is summarized in Table 5.11. [84,90].

Table 5.11. GAP population, net growth and migration rates.

Year	GAP Urban Population	GAP Rural Population	Net migration % per year	Urban Population Increase % per year	Rural Population Increase % per year
1980	1662222	1905406	-3.4	3.7	0.8
1985	2148448	2155119	-2.2	5.1	2.4
1990	2870250	2287762	- 3.3	5.8	1.2
1997	3926509	2202464	-	4.6	-0.5

Prior to 1990, total fertility rate (average number of children born to each woman during her lifetime) is about 5 [83]. As the data summarized in table implies, net birth rate in the region is so high that although there exists emigration, growth rate of population growth accounts to a doubling time of about 20 years.

Major population dynamics in the region are emigration, i.e., migration from urban and rural regions to exregion and migration from rural GAP to cities and towns of the region. According to data, by 1997, GAP population reached to about 10% of population of Turkey.

V.2.12.1. Population Sector Description

GAPSIM population sector evaluates size of population living in subsettlements and villages and size of population living in towns and cities with respect to specific net birth, emigration and immigration rates determined under urban job availability and rural subsistence level constraints. This sector consists of two stock variables representing rural population (rpopulation) and urban population (upopulation) and their associated net birth and migration flows (see stock - flow structure in Figure 5.35.).

Stock variables in GAPSIM population sector are

rpopulation: population living in villages and subsettlements (capita).

upopulation: population living in cities and towns (capita).

and flow variables are

rural_netbirth: net birth rate in rural GAP (capita/year).

urban_netbirth: net birth rate in urban GAP (capita/year).

rural_emigration: emigration rate from rural GAP to exregion (capita/year).

urban_migration: migration rate in between urban GAP and exregion (capita/year).

inregional_migration: migration rate in between rural and urban GAP (capita/year).

Major converters in population sector are

normal_rural_emig_fract: normal fraction for emigration from rural GAP set as 0.037 according to historical data (1/year).

normal_inreg_mig_fract: normal fraction for migration in between rural and urban GAP set as 0.045 according to historical data and isolated run results eliminating factors effecting migration rates (1/year).

nurmal_urban_mig_fract: normal fraction for migration in between urban GAP and exregion set as 0.033 according to historical data (1/year).

subsistence_ratio: ratio of local rural food consumption to regional food production measured in terms of cereals, pulses and summer cereals (unitless).

subsistence_eff_rural_emig: effect of subsistence ratio on rural_emigration (1/year).

subsistence_eff_inreg_mig: effect of subsistence ratio on inregional migration (1/year).

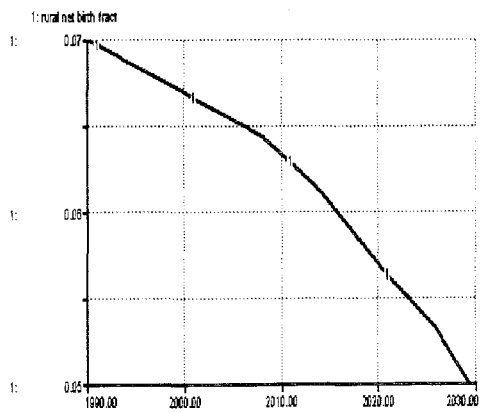
exregional_job_avail: a constant representing job availability outside the region (unitless)

job_avail_ratio: ratio of urban_job_avail imported from urban sector to exregional_job_availability (unitless)

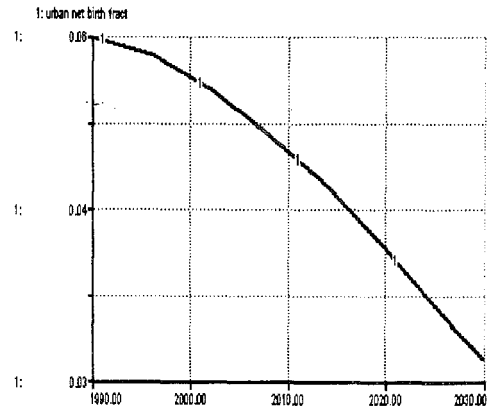
job_avail_ratio_mult_urban_mig: effect of job avail ratio on urban migration rate (1/year).

jobs_attract_eff_inreg_mig: effect of urban_job_avail on inregional_migration (1/year).

rural_net_birth_fract: net birth fraction for rural GAP (1/year). This variable is set as a time function assuming that, high birth rate will follow a declining trend:



urban_net_birth_fract: net birth fraction for urban GAP (1/year). This variable is set as a time function, assuming that, birth rate will follow a declining trend:



pop_firewood_demand: firewood demand generated by population, a variable exported to forests sector (ton/year).

In GAPSIM, population dynamics are controlled by four main negative feedback loops (see causal loop diagram in Figure 5.34.). As size of rural population increases, local food consumption increases. The increase in local food consumption with respect to regional food production measured by the variable subsistence ratio stimulates rural emigration which results in decreasing rural population. This constitutes the firs negative feedback. Secondly, increasing local food consumption has similar effect on inregional migration via subsistence ratio. This process again, results in decreasing rural population and completes the second negative feedback. The third and fourth negative feedback loops control the urban population size. As urban population increases, urban job availability decreases and inregional migration from rural GAP to urban GAP decreases. This results in decreasing urban population and completes the third negative feedback. Similarly, decreasing job availability increases the attractiveness of exregion which is measured by the variable job availability ratio. As the attractiveness of exregion increases urban migration rate increases and urban population decreases. This process constitutes the fourth negative feedback acting on GAP population dynamics. Here again, dashed circles enclose the variables belonging to sectors of the model other than population sector.

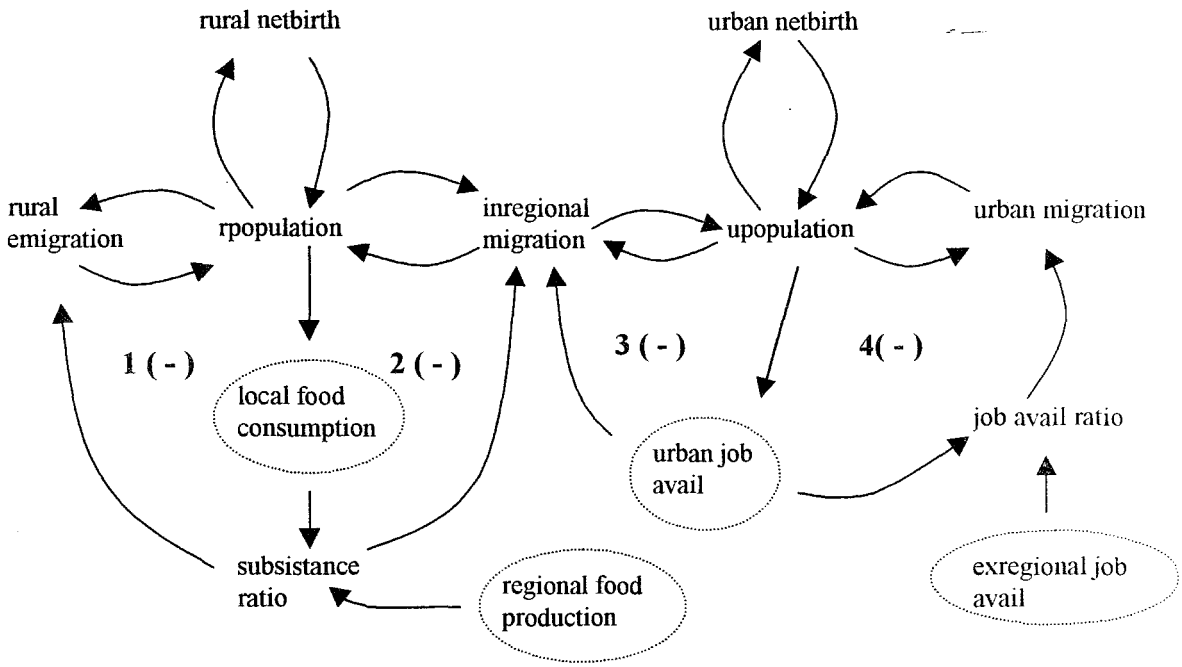


Figure 5.34. Causal loop diagram for GAPSIM population sector.

Stock-flow diagram for GAPSIM population sector is presented in Figure 5.35.

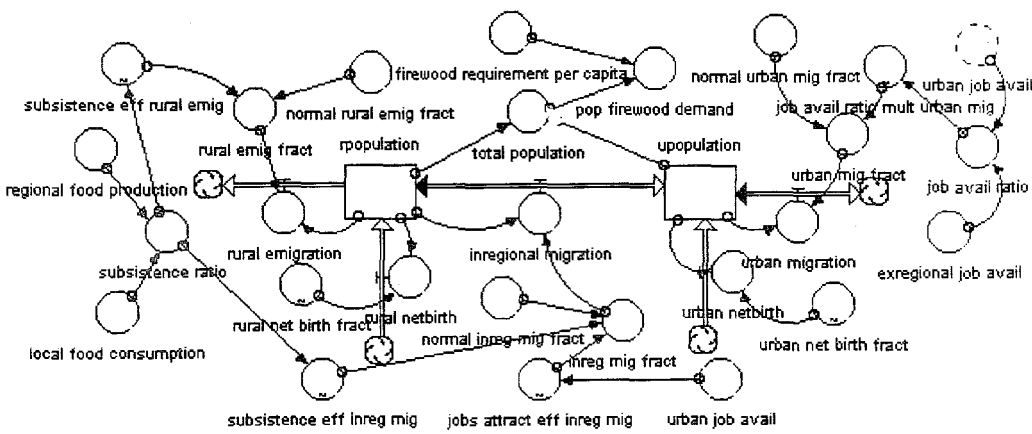
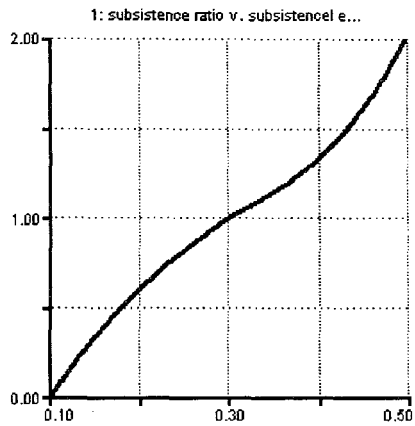


Figure 5.35. Stock-flow structure of GAPSIM population sector.

In GAPSIM population sector, effect of changing subsistence ratio on rural emigration rate is formulated by the graphical function susbsistence_eff_rural_emigration. In the model, subsistence ratio is measured as the ratio of local food consumption to regional food production and increasing local consumption with respect to food production is taken as an indicator of increasing emigration:

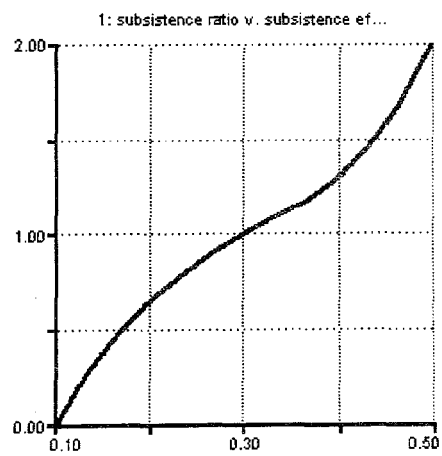


Then,

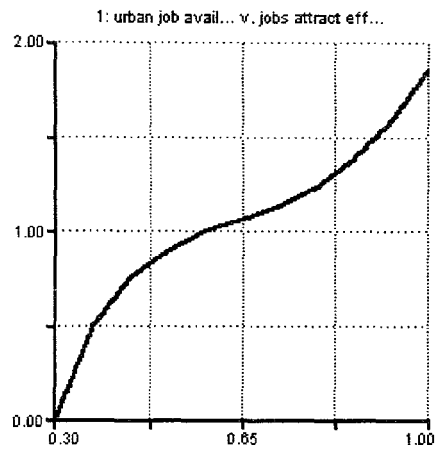
rural_emig_fract=normal_rural_emig_fract*subsistence_eff_rural_emig (1/year) and

rural_emigration=rpopulation*rural_emig_fract (capita/year)

The rate of inregional migration is formulated by considering both the effects of subsistence ratio and urban job availability. Similarly, the effect of subsistence level is formulated by the graphical function subsistence_eff_inreg_mig:



Increasing urban job availability is taken as a stimulating effect on migration rate from rural to urban GAP. But since inregional migration is formulated as a biflow, it is assumed that, decreasing urban job availability may also stimulate migration from urban to rural gap. This effect is formulated by the graphical function jobs_attract_eff_inreg_mig:

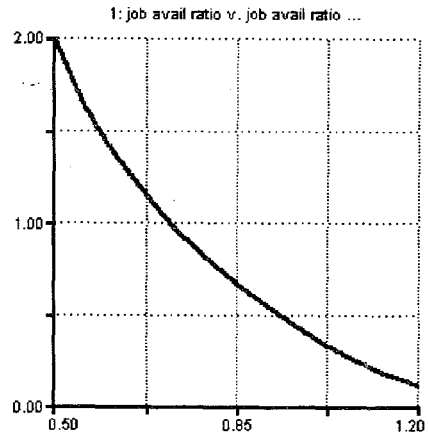


Then,

inreg_mig_fract=normal_inreg_mig_fract*subsistence_eff_inreg_mig*jobs_attract_eff_inreg_mig (1/year) and

inregional_migration=IF(inreg_mig_fract>=0)THEN(rpopulation*inreg_mig_fract)ELSE(upopulation*inreg_mig_fract) (capita/year)

The flow variable urban_migration is formulated as a function of job availability ratio which creates a relative attractiveness between urban GAP and exregion in terms of job availabilities. Job availability ratio is calculated as the ratio of urban_job_avail to exregional_job_avail and job_avail_ratio_mult_urban_mig is formulated as a function of job_avail_ratio. As this ratio increases, urban GAP becomes attractive for immigration and as this ratio decreases exregion becomes more attractive:



Then,

urban_mig_fract=normal_urban_mig_fract*job_avail_ratio_mult_urban_mig (1/year) and

urban_migration=upopulation*urban_mig_fract (capita/year)

V.2.13. Market Sector

In GAP region, the agricultural products are sold through different markets. These are local markets in small towns, large markets in the cities and the transaction places of governmental enterprises, cooperatives and industries. Also, in some of the cities, there exists official stock markets established according to the legislations of Chamber of Commerce [28]. Although, basically, the prices of agricultural commodities are determined in free market conditions, certain governmental enterprises and cooperatives intervene this process by making certain amount of purchases according to the governmentally fixed bottom prices. The effect and importance of these interventions change for different commodities depending on the power of the relevant organization. These enterprises buy the products, establish inventories and sell them in national and international markets. The utilization and intervening enterprises for basic commodities are summarized in the Table 5.12 [4,28].

Table 5.12. The utilization and intervening enterprises for basic commodities in GAP region.

Commodities	Basic Utilization	Intervening Enterprises
wheat	flour, macaroni, semolina	TMO
barley	feed, industrial feed, malt extract	TMO
pulses	direct consumption	TMO, Güneydoğubirlik
cotton	textile	Çukobirlik
corn	feed industry	TMO
maize	feed industry	TMO
oil crops	oil industry	
vegetables	food industry, direct consumption	
pistachio	direct consumption	Güneydoğubirlik
grape	wine, direct consumption	Güneydoğubirlik
milk	diaries, direct consumption	TSEK
livestock	diaries, direct consumption	EBK

State subsidies for agricultural production factors constitute the second major form of governmental intervention to the agricultural economy in Turkey [91]. In recent years, subsidy was applied to about 15% of agricultural inputs. There exists state enterprises and agricultural credit cooperatives such as TMO, TKK, TSK and TZDK which supply fertilizers, seeds and saplings and pesticides to the farmers with low prices.

V.2.13.1. Market Sector Description

GAPSIM market sector is an aggregation of agricultural markets in GAP region where prices of major commodities are determined with respect to an availability criteria based on total regional supply and total regional demand (see stock - flow structure in Figure 5.37.). These commodities are the aggregated products produced in arable lands and rangelands. Commodities in GAPSIM market model and sources of their regional supply and regional demand are tabulated in Table 5.13. All the commodities are supplied from arable lands and rangelands sectors and they are demanded by industry in urban sector and exported.

Table 5.13. Agricultural commodities in GAPSIM market sector, sources of their supply and demand.

commodity	sources of supply	sources of demand
cereals	CERF, CEPRF, CESIF, CCSPIF	urban industry and export
pulses	CEPRF, CCSPIF	urban industry and export
cotton	COIF, COSIF, CCSPIF	urban industry and export
oil crops	COSIF, CESIF, CCSPIF	urban industry and export
summer cereals	COSIF, CESIF, CCSPIF	urban industry and export
vegetables	COSIF, CESIF, CCSPIF	urban industry and export
fruits	RFWG, IRWG	urban industry and export
milk	rangelands and farmlands	urban industry and export
livestock	rangelands and farmlands	urban industry and export

The initial prices for these commodities for year 1990 are estimated from "SIS Agricultural Structure 1990" [92]. The prices for agricultural products constituting a single commodity in GAPSIM are averaged and discounted for September 1997 prices according to "State Institute of Statistics" general price index. These values are further averaged according to the values given for different provinces of the region.

The prices of agricultural production factors involved in cost calculations in agriculture sectors are taken as constants. These factors consist of nitrogen fertilizer (ammonium nitrate 26%), phosphate fertilizer (triple superphosphate 43%), pesticides (general effective material), seeds for all crop aggregations, fuel, labor (seasonal labor). Prices for fertilizers, seeds, fuel and seasonal labor are estimated from TOKB [93], pesticides from GAP Master Plan [94] and water from GAP BKIB report [95]. All prices are discounted to September 1997 prices according to "State Institute of Statistics" general price index.

The price mechanisms for individual commodities in GAPSIM market sector are similar. Among nine commodities, only variables related with cereals are given. The stock variables are the prices for individual agricultural commodities in the model.

cereals_price: price of cereal products (TL/kg), calculated by a first order smoothing of indicated_price_cereals.

Flow variables are the price changes acting on prices of individual commodities.

cereals_price_change: change in price of cereal products (TL/kg/year).

Major converters related with cereals are

cereals_total_supply: regional supply of cereal products (kg/year).

agroout_ind_cereals_dem: cereals demand created by agroout_ind_struct in urban sector (TL/year).

exregion_cereals_dem: cereals demand created by exregion (TL/year).

cereals_demand: summation of agroout_ind_cereals_dem and exregion_cereals_dem after unit conversion (kg/year).

cereals_gov_purchase: governmental purchases for cereals determined according to governmental purchases percent exported from government sector (kg/year).

cereals_total_dem: total demand for cereal products (kg/year). This variable is calculated as a summation of cereals_demand and cereals_gov_purchase.

cereals_availability: availability of cereals in regional market indicating price change (unitless). This variable is calculated as a ratio of cereals_total_supply to cereals_total_dem.

indicated_price_cereals: cereals price indicated according to cereals_availability (1/year)

exregion_dem_agr_goods: total demand for export in market (TL/year). This variable is set as a time function, where two different scenarios for export are used in the base run. For no water resources development (no GAP scenario) exregional demand increases by a factor of 1.5 till 2030 and for scenario involving GAP, it increases by a factor of 2.5.

agroout_ind_rawmat_dem: total demand for industrial processing in urban sector (TL/year). This variable is exported from urban sector.

cer_ind_fract: fraction of cereals_supply processed in urban agroout_ind_struct (fraction)

cer_export_fract: fraction of cereals_supply exported to exregion (fraction).

agr_agroout_ind_rawmat_supply: regional total supply of agricultural commodities for urban agroout_ind_struct (TL/year).

agr_exregion_supply: regional total supply of agricultural commodities for export (TL/year).

agr_agroin_ind_dem: agricultural demand for production factors from urban agroin_ind_struct (TL/year). This variable is calculated through total costs of individual land stocks in arable lands sectors.

summer_crops_avail: a variable exported to water resources sector, indicating average availability of summer crops in GAP regional market (unitless).

second_crops_avail: a variable exported to arable lands sector indicating average availability of crops suitable for second cropping in GAP regional market (unitless).

In GAPSIM market model, basically two negative and one positive feedback loops characterize the dynamics acting on commodity prices. These feedback loops are presented on the basis of cereal prices in Figure 5.36. Among these feedback loops, first loop is already described in section V.2.1.1 and the third loop is described in section V.2.11.2. The large positive feedback loop number two is peculiar to GAPSIM. According to this mechanism, as cereals price increases, it increases cereals total supply through a succession of causalities (loop number one), and this increases rawmaterial supply for agroout industry structures in urban sector. Then, this stimulates industrial growth according to the basic premises of GAP regional development and agroout industry rawmaterial demand increases. This result in increasing demand for cereals and decreasing availability of cereals implying higher prices.

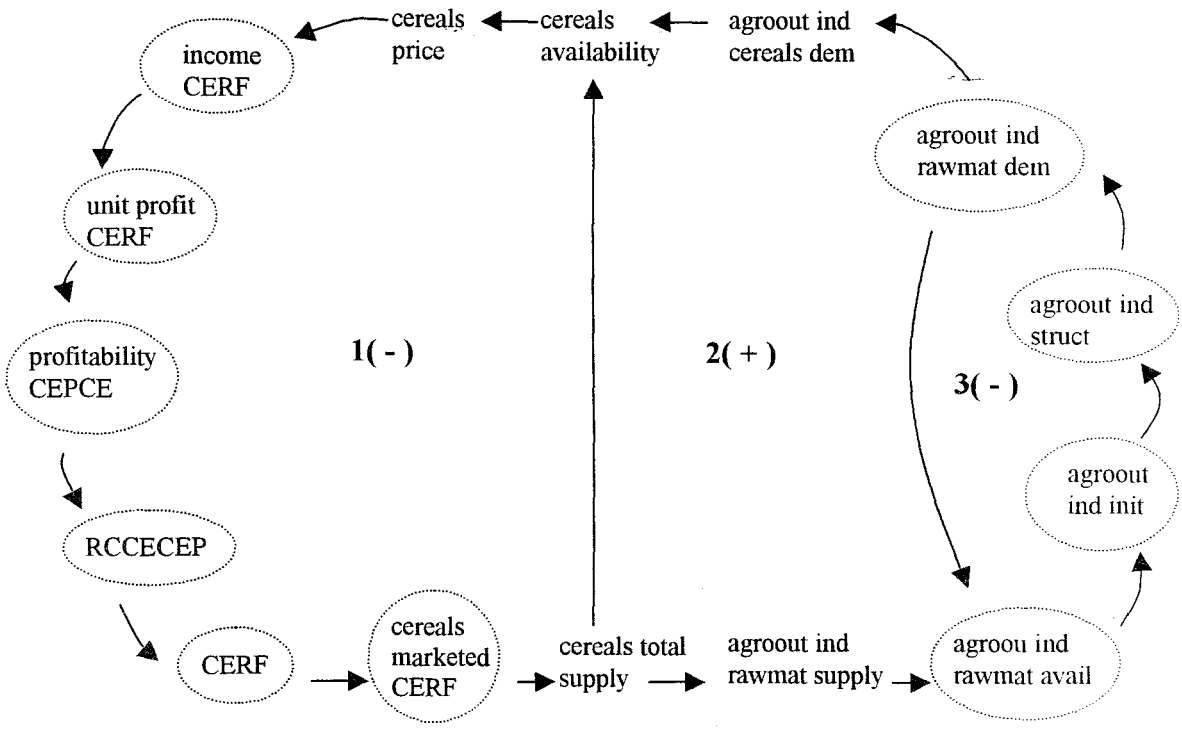


Figure 5.36. Causal loop diagram for GAPSIM market sector.

Simplified stock-flow structure of market sector is given in Figure 5.37. Again, Only variables related with cereals are considered since all price mechanisms are similar.

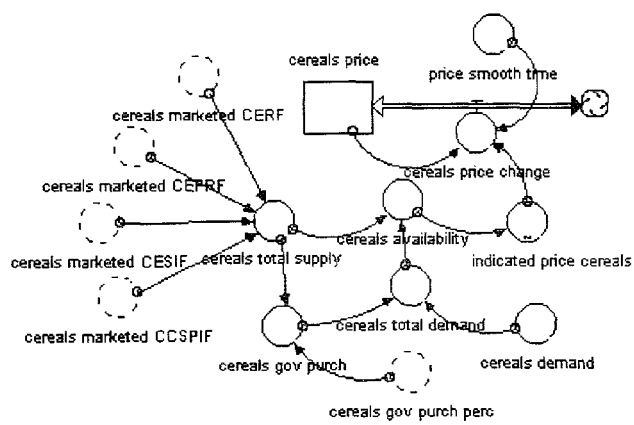
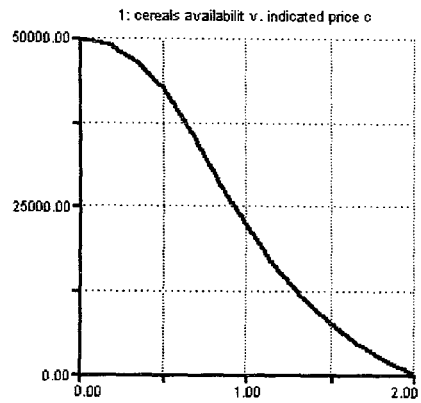


Figure 5.37. Simplified stock-flow structure of GAPSIM market sector.

In GAPSIM market sector, indicated prices of individual commodities are evaluated as a function of their availability. For example, for cereals, as availability of the commodity increases, it will be cleared from market at lower prices (TL/kg) and if it decreases, then it will be possible to sell the commodity to the consumers at higher prices:



Then, commodity prices are determined by a first order two years smoothing of indicated prices.

5.2.13.2. Market Sector Simulation Runs

In this section, behavior of price and availability for certain commodities and land flows corresponding two basic scenario, "no water resources development (no GAP)" and "with water resources development (with GAP)" are demonstrated. In these runs environmental factors such as irrigation and salinisation, fertilizers, pesticides and erosion are eliminated.

Commodity prices in GAPSIM market sector have two basic mode of behavior. These are presented in Figure 5.38. on the basis of cotton prices. In run (a), price (TL/kg), availability (unitless) supply (kg/year) and demand (kg/year) for cotton is simulated under "no GAP" conditions and in run (b) same variables are simulated under "with GAP" conditions. According to the first run (a), as there exists an increase in regional population and a moderate urban growth leading to stagnation, demand increases, availability

decreases and price indicated by the availability increases. In response, cotton production increases but can not compensate increasing demand because of the constraints of agricultural system under "no GAP" conditions. According to the second run (b), after initiation of water resources development, there is increase in cotton production which stimulates industrial growth and increasing demand for cotton. But, increasing demand is delayed by industrial growth process, therefore, availability first increases, then decreases and price first decreases and then increases.

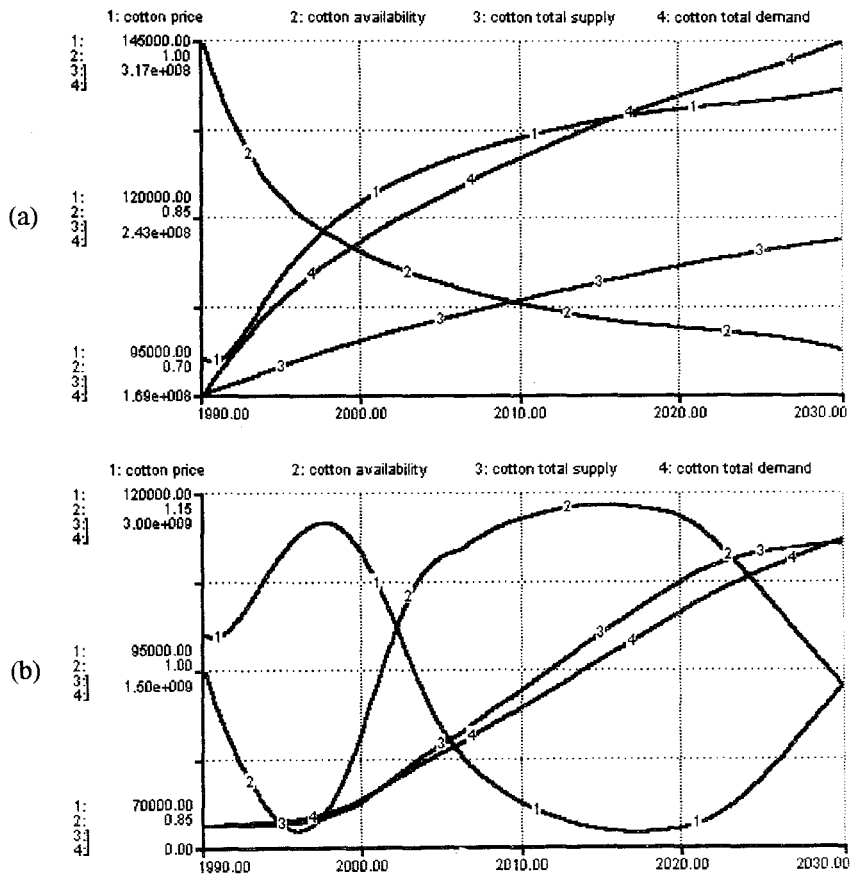


Figure 5.38. Behavior of parameters related with cotton under "no GAP" and "with GAP" conditions.

V.2.14. Government Sector

GAPSIM government sector does not intend to model government but it is a sector from where certain policy alternatives related with (a) water resources development and water releases; (b) rangeland improvement; (c) forest plantation; (d) public

employment; and (e) government purchases in the market are tested. Feedback mechanisms do not act on this sector, therefore, unidirectional interventions are conducted.

Policy variables in GAPSIM government sector are restated below, beginning with the variables related with water resources sector.

(A) Variables related with water resources development:

GAP_const_coeff: GAP construction coefficient (unitless), a constant between 0 and 1, representing modifications in targeted GAP constructions within the simulation period. This constant is set as one in the base run.

irr_schemes_construction_delay: time factor representing delay in irrigation schemes development (years). This variable is set as 1 in the base run.

irr_priority_in_operation: a constant between 1 and 2 indicating priority of irrigation to hydropower production, 1 representing the highest priority for irrigation, i.e., all the demand is tried to be satisfied if it does not exceed capacity (unitless). This variable is set as 1 in the base run.

(B) Variables related with rangelands improvement:

poor_range_imp_fract: a fraction government policy on poor rangelands improvement (1/year), representing fraction of poor rangelands that will be improved to rich_rangelands. This variable is set as 0 in the base run.

dest_range_impr_fract: similar to the variable poor_range_impr_fract (1/year). This variable is set as 0 in the base run.

(C) Variables related with forests plantation:

desired_grove_land: a variable indicating desired quantity of grove lands for each year according to a fixed long term forestation program (ha). This variable is set according to data in the base run [4].

grove_planting_fract: a variable indicating rate of forestation according to the desired quantity of grove lands (1/year), initially set to 0.1.

desired_heath_land: similar to the variable desired_grove_land (ha). This variable is set according to data used for desired_grove_land.

heath_planting_fract: similar to the variable grove_planting_fract (1/year), initially set to 0.1.

(D) Variables related with employment:

desired_urban_job_avail: a policy variable indicating desired employment (unitless). This variable is initially set to 0.65.

(E) Variables related with government purchases of agricultural commodities.

cereals_gov_purch_perc: percentage of marketed cereals purchased by government enterprises (unitless). This variable is set to 15 % in the base run.

Other variables related with government purchases of agricultural commodities are similar to cereals_gov_purch_perc but their values differ according to the conventional government interventions followed in Turkey. For example, government purchase percentage for livestock products are set as 2% in the base run since state subsidy for these commodities are low.

V.2.15. Calculations Sector

Calculations sector include miscellaneous calculations concerning arable lands sectors, land flows, population and livestock, profits and market. In this section, these calculations related with model assumptions are explained.

V.2.15.1. Calculations Concerning Arable Lands

(A) Calculations for crop consumptive-use.

Consumptive-use or evapotranspiration describes the total water removed from an area by transpiration and evaporation from soil, snow and water surfaces. For certain

climatic conditions, consumptive use values can be calculated theoretically for individual crops for determination of crop irrigation requirements and design of irrigation systems. Here, in calculation of crop consumptive-use for each irrigated land stock, crop consumptive-use values for individual crops calculated according to Blaney - Criddle method by State Water Works (DSI) are used [96]. The weight of each crop in field rotation and percentage of land allocated for second crops determines the consumptive-use for each land stock according to the following calculations:

crop_cons_use_COIF=cotton_consumptive_use+land_util_perc_sec*fodder_consumptive_use (mm/year)

crop_cons_use_COSIF=0.5*cotton_consumptive_use+(0.5+land_util_perc_sec)*(fodder_consumptive_use+oil_crops_consumptive_use+sum_cer_consumptive_use+vegetables_consumptive_use)/4 (mm/year)

crop_cons_use_CESIF=0.5*cereals_consumptive_use+(0.5+land_util_perc_sec)*(fodder_consumptive_use+oil_crops_consumptive_use+sum_cer_consumptive_use+vegetables_consumptive_use)/4 (mm/year)

crop_cons_use_CCSPIF=0.25*cereals_consumptive_use+0.25*cotton_consumptive_use+0.25*pulses_consumptive_use+(0.25+land_util_perc_sec)*(fodder_consumptive_use+oil_crops_consumptive_use+sum_cer_consumptive_use+vegetables_consumptive_use)/4 (mm/year)

crop_cons_use_IRWG=900 (mm/year)

Consumptive-use variables (crop_cons_use_COIF, etc.) for each land are used in irrigation and salinisation sector for determination of crop irrigation requirements.

(B) Calculations for normal phosphate application.

In calculation of normal phosphate application for each land stock, actual phosphate (P_2O_5) consumption norms for cereals, pulses and fodder crops and fruits are taken into account for rainfed fields and rainfed wine-garden [4,30,32].

normal_phosphate_CERF=12 (kg/ha/year)

normal_phosphate_CEPRF=12 (kg/ha/year)

normal_phosphate_RFWG=100 (kg/ha/year)

For irrigated fields and irrigated wine-garden, proposed phosphate (P_2O_5) consumption norms for cereals, pulses, fodder, cotton, oil crops, summer cereals and vegetables are considered [28,32]. Then, normal phosphate application for each land stock is calculated according to the weight of each crop in respective rotation.

normal_phosphate_COIF=phosphate_cotton (kg/ha/year)

normal_phosphate_COSIF=0.5*phosphate_cotton+0.5*(phosphate_fodder+phosphate_oil crops+phosphate sum cer+phosphate vegetables)/4 (kg/ha/year)

normal_phosphate_CESIF=0.5*phosphate_cereals+0.5*(phosphate_fodder+phosphate_oil _crops+phosphate_sum_cer+phosphate_vegetables)/4 (kg/ha/year)

normal_phosphate_CCSPIF=0.25*phosphate_cereals+0.25*phosphate_cotton+0.25*phosphate_pulses+0.25*(phosphate_fodder+phosphate_oil_crops+phosphate_sum_cer+phosphate_vegetables)/4 (kg/ha/year)

normal_phosphate_IRWG =(phosphate_grape+phosphate_pistachio)/2 (kg/ha/year)

normal_phosphate_seconds=(phosphate_fodder+phosphate_oil_crops+phosphate_sum_cer +phosphate_vegetables)/4 (kg/ha)

For the calculation of fertilizer costs in arable lands sectors, phosphatic material triple superphosphate with its grade ratio 43% phosphate (P_2O_5) is considered. The variables normal_phosphate are used in fertilizers sector.

(C) Calculations for normal nitrogen application.

For rainfed fields and rainfed wine-garden actual consumption norms [4,30,32] for irrigated fields and irrigated wine-garden proposed quantities [28,32] are taken as nitrogen (N) requirements of individual crops. Normal nitrogen for each land stock (kg/ha/year) is calculated as it is done for P_2O_5. While calculating fertilizer costs in arable lands sectors, nitrogen carrying material ammonium nitrate with its grade ratio 26% N is considered. The variables normal_nitrogen variables are used in fertilizers sector.

(D) Calculations for normal pesticides application.

For rainfed fields and rainfed wine garden actual pesticide consumption norms [30], for irrigated fields and irrigated wine-garden probable application rates used in value added calculations [94] are taken as requirements of individual crops. Here, pesticides refer to average quantities of several insecticides, herbicides and fungicides in terms effective material. Normal pesticides for each land stock (kg/ha/year) is calculated as it is done for normal phosphate quantities. The variable normal_pesticides is exported to pesticides sector.

(E) Calculations for fuel consumption.

For individual crops, tabulated machine power requirements are considered [32]. The data in terms of hours/decar/year are converted to lt oil/hectare/year by multiplying 10 decar/hectare and by 5 lt oil/hour. Fuel for each land stock is calculated as it is done for normal phosphate quantities. Fuel variables (fuel_COIF, etc.) are exported to arable land sectors and are involved in cost calculations.

(F) Calculations for labor requirement.

For individual crops, peak labor requirements are considered [4]. These Figures in terms of man-day/ha are based on moderate mechanization levels and for irrigated crops 2 man-day/ha is added. Labor variables (labor COIF, etc.) are exported to arable land sectors and are involved in cost and labor requirement calculations.

(G) Calculations for seed and sapling.

For individual crops, seed and sapling requirements and relevant seed replenishment periods are considered [33] and these variables (cereal seeds, etc.) in terms of kg/ha/year are exported to arable land sectors for cost calculations.

(H) Calculations for crop constants.

For calculation of crop constants of individual farms, two assumptions are made, one considering marketing safety and local consumption advantage of individual crops and other considering know-how requirements of individual farm systems. For marketing safety and local consumption advantage, crop_priority_constant (unitless) is taken to be 1 for cereals and pulses and summer cereals, 1.5 for cotton and oil crops and 2 for vegetables and fruits. For know-how requirements single_farm_constant, two_farm_constant, multi_farm_constant and wine_garden_constant (unitless) are used and taken to be 1, 1.5, 2 and 2 respectively. Then crop constant for an individual farm is calculated as for example

COSIF_crop_const=(cotton_priority_constant+(oil_crops_priority_constant+sum_cer_priority_constant+vegetables_priority_constant)/3)*0.5*two_farm_constant (unitless)

(I) Calculations for water costs.

For irrigation water cost calculations of each irrigated land stock, first, water price for each crop is considered (TL/ha/year) [95], then, water cost for that land stock is calculated as for example

water_cost_COIF=(water_price_cotton*COIF)+1/2*COIF*land_util_perc_sec*(water_price_fodder) (TL/year)

In these calculations water cost for second crops are discounted by 50% [95].

V.2.15.2. Calculations Concerning Land Flows

(A) Calculations for transformation from rainfed to irrigated farming.

For calculations of flow variables representing transformation of rainfed fields and wine garden to irrigated fields and wine garden, first, flow variable irrigation_development is exported from water resources sector and this variable is shared among rainfed land stocks with respect to their relative weight in hectares. Then, the same

variable is shared among irrigated land stocks and the flow values for individual stocks are exported to arable lands sectors.

(B) Calculations for other land flows.

For calculations of flows from rangelands to individual rainfed field stocks, first the land flows generated in rangelands sector are imported and their summation is shared among rainfed field stocks with respect to their relative weight in terms of hectares.

Same procedure is followed for calculation of flows from forest sector to individual arable land stocks.

V.2.15.3. Calculations Concerning Population and Livestock

(A) Calculations for rural population.

Rural population is distributed among individual arable land stocks in order to calculate local consumption and labor on each farm system. Rural population variable imported from population sector is shared among arable land stocks with respect to relative weight of each stock in terms of hectares.

(B) Calculations for sheep on farmlands.

For distribution of livestock among field stocks additional assumptions are used. For each field stock, unit fodder potential (kg/ha/year) is generated. For example unit fodder potential for COSIF is

COSIF_unit_fodder_potential=10000*(0.25+land_util_perc_sec) (kg/ha/year)

where it is assumed that, half of land for summer crops and land for second cropping can be allocated for fodder production. In this formulation 10000 stands for dry yield of fodder crops (kg/ha/year) on irrigated fields. Then, fodder potential for COSIF is calculated as

COSIF_fodder_potential= COSIF*COSIF_unit_fodder_potential (kg/year)

The variable sheep_on_farmlands is distributed among field stocks according to their respective weight in terms of fodder potential and exported to rainfed fields and irrigated fields sectors.

V.2.15.4. Calculations Concerning Profits

(A) Profit calculations for flows in between fields and wine-garden.

In calculation flows from fields to wine-garden, aggregate profit values for rainfed fields and irrigated fields are used. For example, profit for rainfed fields is calculated as

profit_RFF_crops=(income_RFF_crops-cost_RFF_crops)/totRFF (TL/ha/year)

(B) Profit calculations between livestock and arable lands

For calculation of rate of switching between sheep on farmlands and crop production on fields, profitability of non-fodder field crops is compared with profitability of sheep on farmlands in rangelands and livestock sector. Profitability of non fodder field crops are calculated as

profitability_non_fod_field_crops=income_non_fod_field_crops/cost_non_fod_field_crops (unitless) where

income_non_fod_field_crops=income_CCSPIF+income_CESIF+income_COSIF+income_COIF (TL/year) and

cost_non_fodder_field_crops=cost_CCSPIF+cost_CESIF+cost_COSIF+cost_COIF (TL/year)

5.2.15.5. Calculations Concerning Market

In market sector, for calculation of rawmaterials supply for industry structures in urban GAP and for commodities supply for export a series of calculations are performed. Here, these calculations are demonstrated on the basis of cereals.

First, cereals total supply (kg/year) is distributed for industrial demand and for export according to fixed fractions, cereals industry fraction (cer_ind_fract) and cereals export fraction (cer_export_fract). Then the quantities cereals supply for industry (cereals_supply_agroout_ind) and cereals supply for export (cer_supply_exregion) are converted to units TL/year by multiplication with initial prices, cereals_initial_price (TL/kg). The summation of supplies of individual commodities (TL/year) constitute rawmaterials supply for industry structures (agroout_ind_rawmat_supply). The same procedure is followed for calculation of supply of commodities for export (agr_exregion_supply).

Also, a series of calculations are performed for distribution of industrial demand for agricultural commodities (agroout_ind_rawmat_dem) among individual commodities in market sector. For this calculation, first, ratios of supply of individual commodities are calculated. For example, cereals supply for industry (TL/year) is divided by total supply for industry (TL/year). Then, industrial demand for agricultural commodities (agroout_ind_rawmat_dem) is shared among the commodities according to these ratios for calculation of cereals demand of industries in TL/year (agroout_ind_cereals_dem). Finally, cereals total demand (kg/year) is calculated as a summation of industrial demand (TL/year) and demand for export (TL/year) with a unit conversion by cereals initial price (TL/kg).

VI. MODEL VALIDATION AND SENSITIVITY ANALYSIS

The aim of this chapter is to demonstrate the validity of GAPSIM, its adequacy in representing GAP with respect to the purpose of the study. A system dynamics model, being a theory-like model, emphasizing causal mechanisms among model variables and components seeks the "right output behavior for right reasons". As system dynamics models are most generally used for policy design and analysis, ultimate objective of the validation procedure is to establish the *structural* validity of the model. Accuracy of the model *behavior* is meaningful only if we have sufficient confidence in the structure of the model.

Although validation in system dynamics is a practice existing in every stage of modeling, a formal validation procedure followed after model construction is also available [97]. For detection of structural flaws in system dynamics models, formal procedures and individual tests called "structure oriented behavior tests" are developed [98,99]. A minimum crucial set of formal tests for validation of system dynamics models are also identified [97]. Behavior validation tests in system dynamics are "weak tests" which do not provide information for structural validity of the model and are therefore useful only after building the confidence on model structure in order to improve the accuracy of behavior. In behavior validity tests, emphasis should be on pattern prediction rather than point prediction, mainly because of the long-term orientation of the models.

In this chapter, validation of GAPSIM is demonstrated on the basis of sector isolated and total runs of the model, concentrating on the "structure-oriented behavior tests" proposed in literature. These are, extreme-condition, behavior sensitivity and phase relationship tests. Extreme-condition tests involves assigning extreme values to selected model parameters and comparing the model generated behavior to the anticipated behavior of the real system under the same extreme condition. Behavior sensitivity test consists of determining those parameters to which the model is highly sensitive and asking if the real system is also sensitive to those set of parameters. In phase relationship test, the phase relationship of two or more variables generated by the model is compared with observed or

expected phase relationships. Any contradictions in these tests point possible structural flaws in the model.

Also, in this chapter, the behavior generated by GAPSIM for the first 8 years of simulation are used for behavioral validation (in section VI.2) whenever relevant data are available for the selected parameters.

VI.1. Validation and Analysis of Selected Sector Groups

In this section, above mentioned formal validation tests are applied on isolated runs of selected sector groups in order to demonstrate their validity under different parameter values.

VI.1.1. Arable Lands Sectors Validation and Analysis

The model sectors, rainfed fields sector, irrigated fields sector and wine-garden sector constitute the arable lands sectors group. In Figure 6.1., the behavior of land stocks in rainfed fields sector, (cereals monoculture on rainfed fields-CERF in hectares, cereals and pulses rotation on rainfed fields-CEPRF in hectares) in irrigated fields sector (cotton monoculture on irrigated fields-COIF, cotton and summer crops rotation on irrigated fields-COSIF, cereals and summer crops rotation on irrigated fields-CESIF and cotton, cereals, summer crops and pulses rotation on irrigated fields-CCSPIF all in hectares) and in wine-garden sector (rainfed wine garden-RFWG and irrigated wine garden-IRWG in hectares) are demonstrated under extreme cereals prices. In this run, cereal prices are set to three times its initial price. In the first graph (a) in Figure 6.1., the land for cereals monoculture (CERF) increases and in (b), the cereals and summer crops rotation (CESIF) dominates. This behavior confirms expected land flows under this extreme condition.

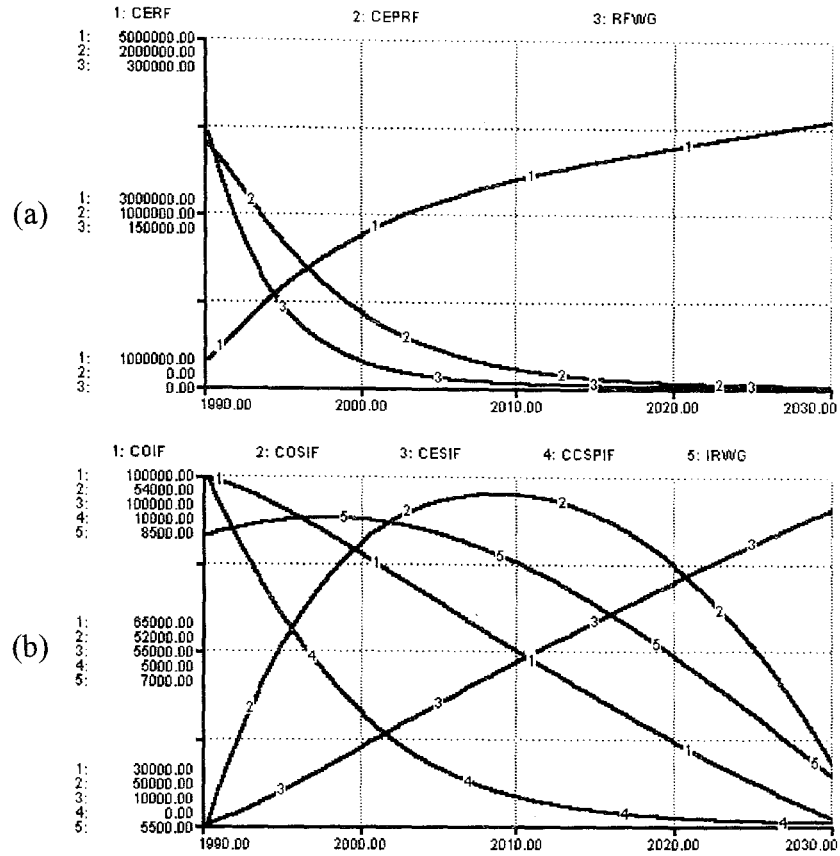


Figure 6.1. Arable lands under extreme cereals price.

In Figure 6.2., this time, another extreme condition is tested. The base yield of cereals in irrigated fields is multiplied by three. The behavior generated in Figure 6.2. again confirms expected behavior, such that, cereals producing lands (CESIF) considerably increase.

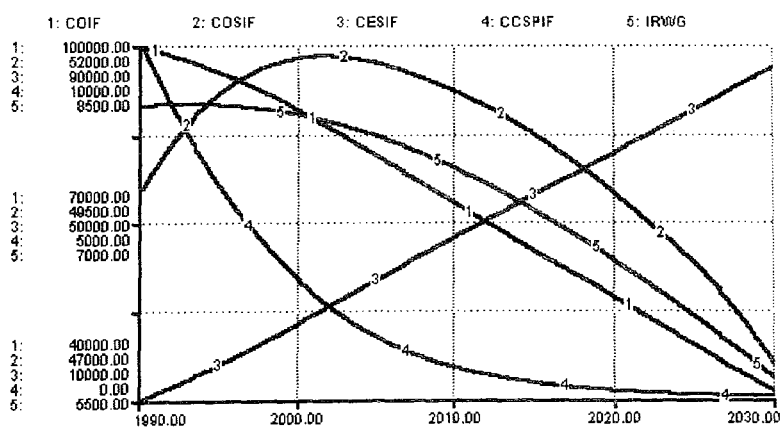


Figure 6.2. Irrigated lands under extreme cereals yield.

In Figure 6.3., sensitivity of land flows to the crop constant parameters is demonstrated. Here, farm constants of COSIF, CESIF and CCSPIF are set to 1 (see section 5.2.15), so that their disadvantage in terms of know-how requirement is eliminated. In reality, this scenario corresponds to increased education and effective farm-extension practices. In this run, it is observed that, the system shifts towards COSIF and CESIF and CCSPIF withstands, corroborating our expectation about the sensitivity of the system to the selected parameter.

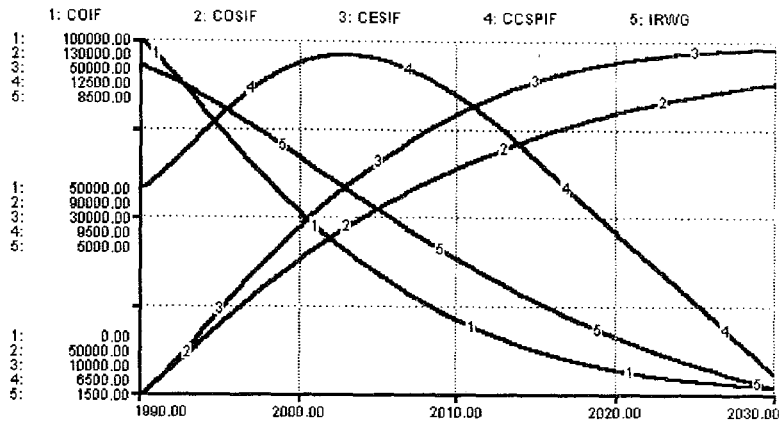


Figure 6.3. Arable lands flows sensitivity to crop constants.

VI.1.2. Irrigation and Salinization Sector Validation and Analysis

In this section, several extreme condition and parameter tests are applied to irrigation and alinization sector. In Figure 6.4., an extreme condition test is demonstrated. In this run, irrigation water application is set to 0 mm and behavior of salt concentration in the root zone, groundwater and irrigation water (all in mg/l) are observed to be in equilibrium. Also, watertable level stays at equilibrium at about -3000 (mm) after an initial adjustment. The behavior of these selected parameters is not contradictory to the theory and model assumptions, such that, precipitation in the model does not contribute to salt accumulation or flushing but it affects groundwater levels.

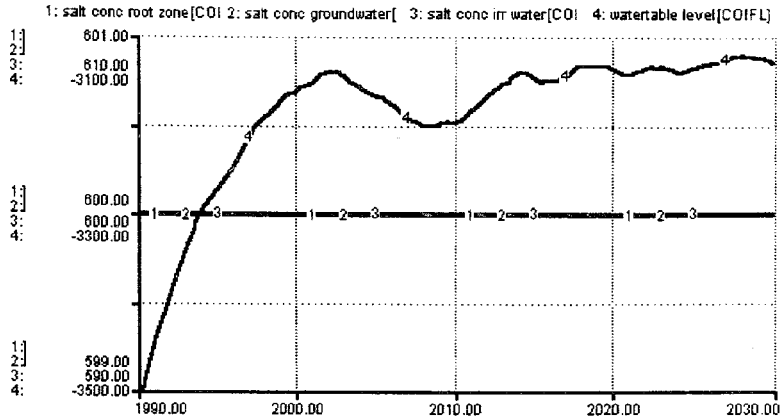


Figure 6.4. No irrigation run for irrigation and salinization sector.

In Figure 6.5., sensitivity of salt concentration at root zone to the salt concentration of freshwater is demonstrated. The runs in Figure 6.5. correspond to freshwater salt concentrations of 400, 600 and 800 (mg/l) respectively. Again, results confirm with theory. As salt concentration of freshwater increases, salt accumulation at root zone increases.

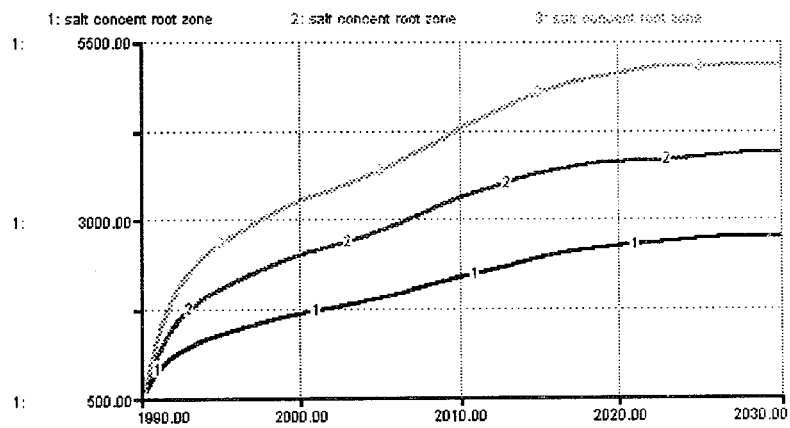


Figure 6.5. Root zone salt concentration sensitivity to freshwater salt concentration.

In Figure 6.6., sensitivity of salt concentration at root zone to crop consumptive use, hence, applied irrigation water is demonstrated. In these runs, crop consumptive use values of 600, 900 and 1200 (mm/year) are used respectively. Here again, as crop consumptive use, hence, irrigation requirements and water application rates increase, salt accumulation at soil root zone increases.

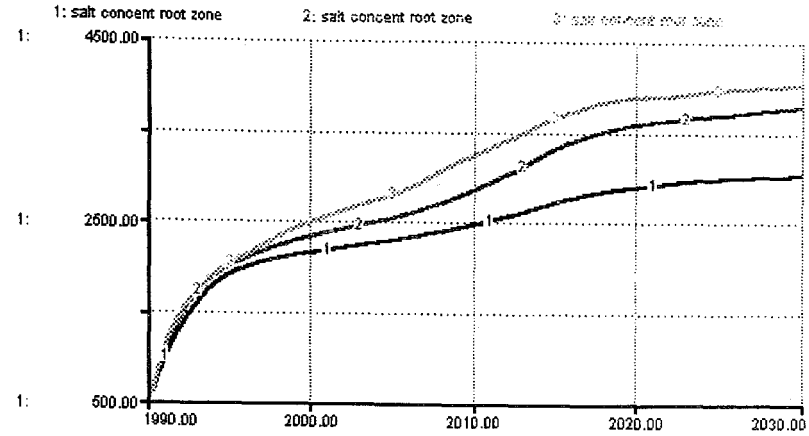


Figure 6.6. Root zone salt concentration sensitivity to crop consumptive-use.

In Figure 6.7., this time, sensitivity to drainage efficiency is demonstrated. In each run, drainage efficiency parameter is set to 0.1, 0.4 and 0.8 (unitless) respectively. As drainage efficiency increases, salt accumulation at soil root zone decreases.

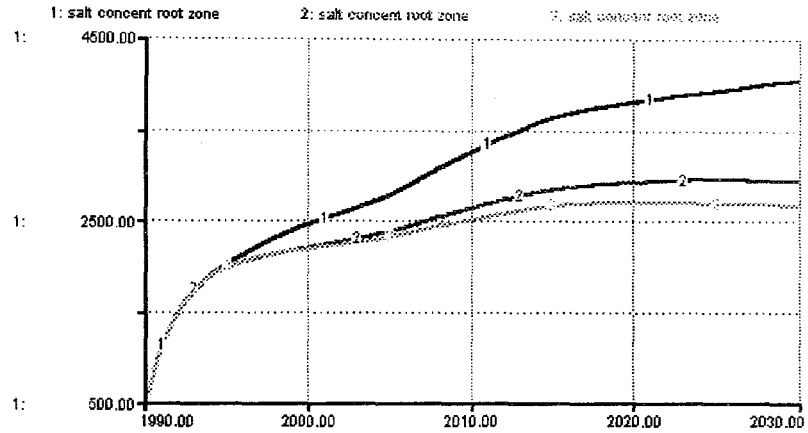


Figure 6.7. Root zone salt concentration sensitivity to drainage efficiency.

Here, once more, we need to mention the purpose dependent characteristic of model validation in system dynamics. Since the purpose of GAPSIM irrigation and salinization sector is to generate soil root zone dynamics and its effect on yields with respect to the weight of different crop consumptive use, drainage efficiency and water availability values and to simulate the ultimate effect of salt accumulation on regional dynamics, the confidence built by these behavior oriented structure tests is sufficient. On the other hand, the behavioral validation for this sector has some technical difficulties, not just because of lacking time series from field studies but also because of the aggregation level that the model holds. In fact, "soil" in GAPSIM does not correspond to any particular

soil in GAP but it is an aggregation of all arable land soils in GAP. Therefore, a statistical comparison of model generated behavior with any available time series may be misleading.

VI.1.3. Fertilizers Sector Validation and Analysis

In Figure 6.8., behavior of yield loss (unitless), nitrogen material application (kg/ha/year) and quantity of leached nitrogen (kg/ha/year) for COIF (cotton monoculture on irrigated fields) are demonstrated under extreme values of nitrogen fertilizers application. In the first graph (a), the fertilizer application rate is set to 0 and it is observed that nitrogen leaching due to fertilizers application is 0 but yield loss is first 0.4 and then gradually falls to 0.34 as fertility decreases because of increasing salinization and soil erosion. This means that if we do not apply any fertilizers, 60% of normal yield is lost at the beginning of simulation and this lost gradually increases as the simulation proceeds.

In the second graph (b), increazing fertilizer application in response to decreasing yields is simulated. This time, at the beginning of the simulation there are no yield losses as sufficient amount of fertilizers are used. Yields are tried to be sustained by increasing fertilizer application resulting in increasing quantity of leaching nitrogen.

The results confirm that, fetilizer model is valid in the sense that, increasing fertilizer application rates help compensating significant yield losses.

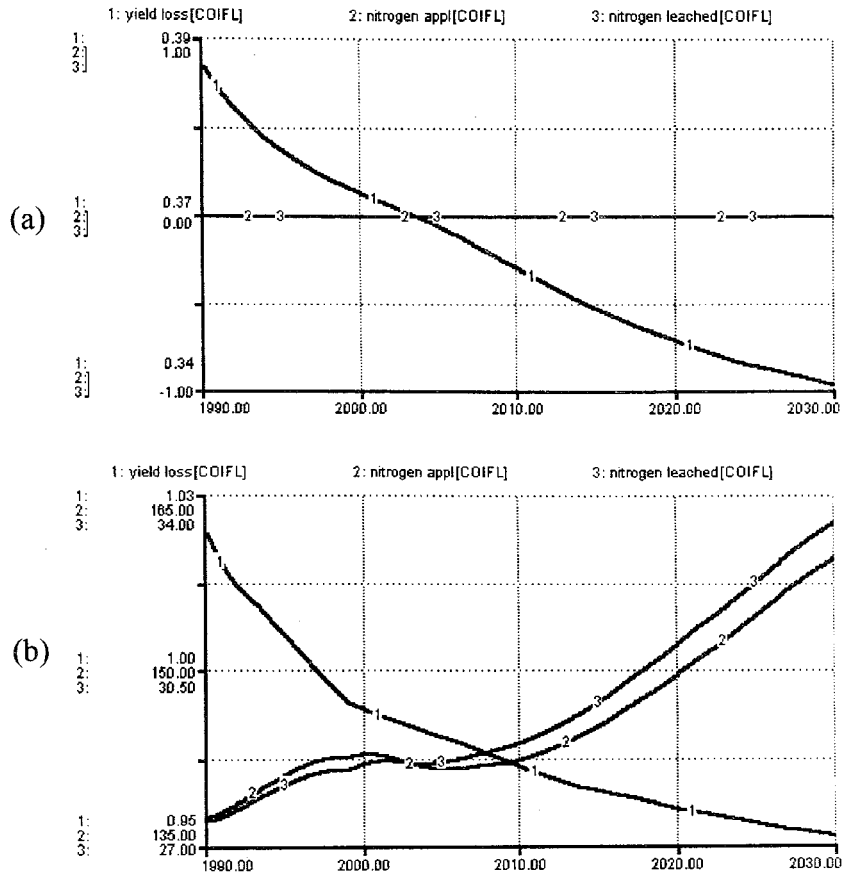


Figure 6.8. Extreme condition tests for fertilizers sector.

VI.1.4. Pesticides Sector Validation and Analysis

Some experiments for validation and analysis of pesticides sector is already demonstrated in section V.2.7.2, during model description. The behavior of the system under those conditions with no monocultural activity duration and pest resistance development effect is confirmed. In this section, further model validation is performed for the extreme condition where no pesticides are applied. In Figure 6.9, the first variable represents average pesticide application rate (kg/ha/year), which is set to 0. Farm residence time oscillates around 2 years, pest density (unitless) is above normal pest density which creates a farm yield loss of about 25%. In this run, as farm residence time converges to a rather small value, under these conditions where no pesticides are consumed, further decrease in farm yields are avoided. If farm residence time were increased, pest density would further increase and would create great reduction in yield.

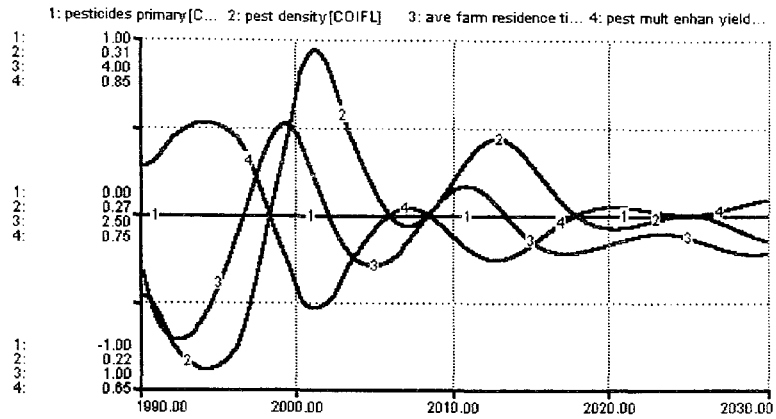


Figure 6.9. Effect of pests on yield if pesticide application is abandoned.

VI.1.5. Rangelands and Livestock Sector Validation and Analysis

In section V.2.8.2, an extreme condition test (no range crowding) and a parameter sensitivity test (range grass cost) is demonstrated for rangelands and livestock sector. In this section, an additional parameter sensitivity tests is performed for range carrying capacities. In this test, carrying capacity of rangelands is halved and results are presented in Figure 6.10. A sharp collapse in rangelands (ha) and a sharp collapse in ranging (sheep) are observed on graphs (a) and (b) because of high range crowding as expected.

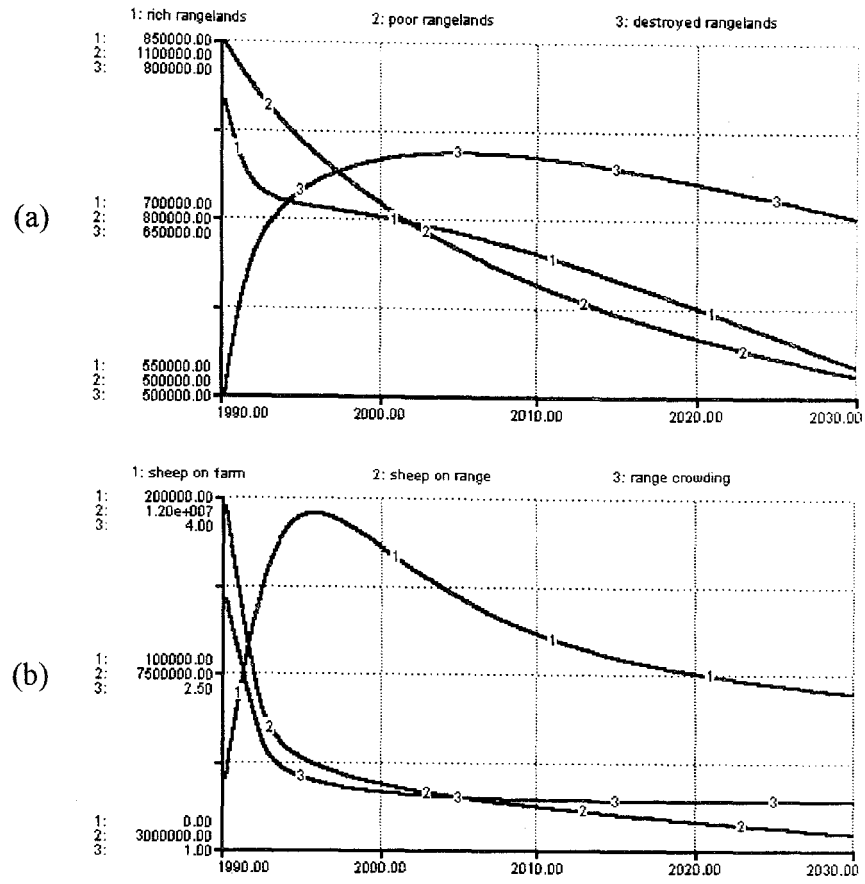


Figure 6.10. Sensitivity of rangelands and livestock to range carrying capacity.

VI.1.6. Forests Sector Validation and Analysis

In Figure 6.11. and 6.12., two extreme condition tests are demonstrated for forests sector. In the first test, population and industry structures are set to 0, so that pressure for land conversion and harvesting is destroyed, and also, planting fraction is set to 0. According to this run (Figure 6.11.), it is observed that, tot forestlands stay constant, mature grove and mature heathlands increase as cleared and young grove and heathlands decline (all in hectares). The second test is based on the assumption of extreme population and extreme industry structures, therefore pressure for land conversion and demand for timber and firewood is high. According to the results illustrated in Figure 6.12., there is a sharp decline in total forest lands, in all grove and all heathland stocks. These two tests confirm our expectations about system behavior under stated extreme conditions.

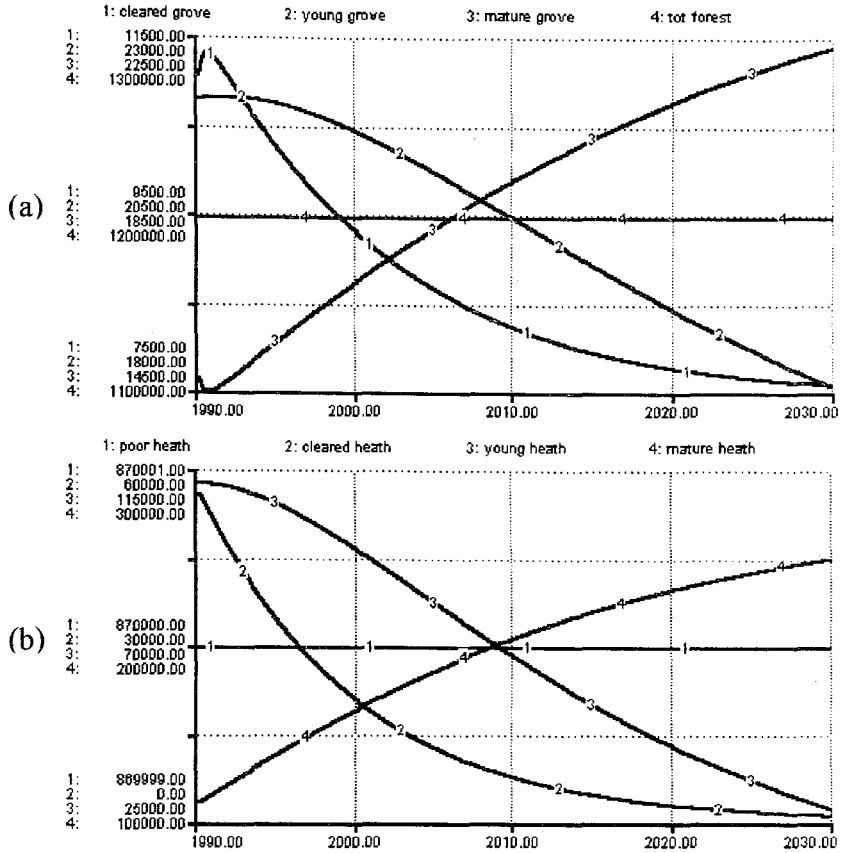


Figure 6.11. Forests under no population, no industry and no planting conditions.

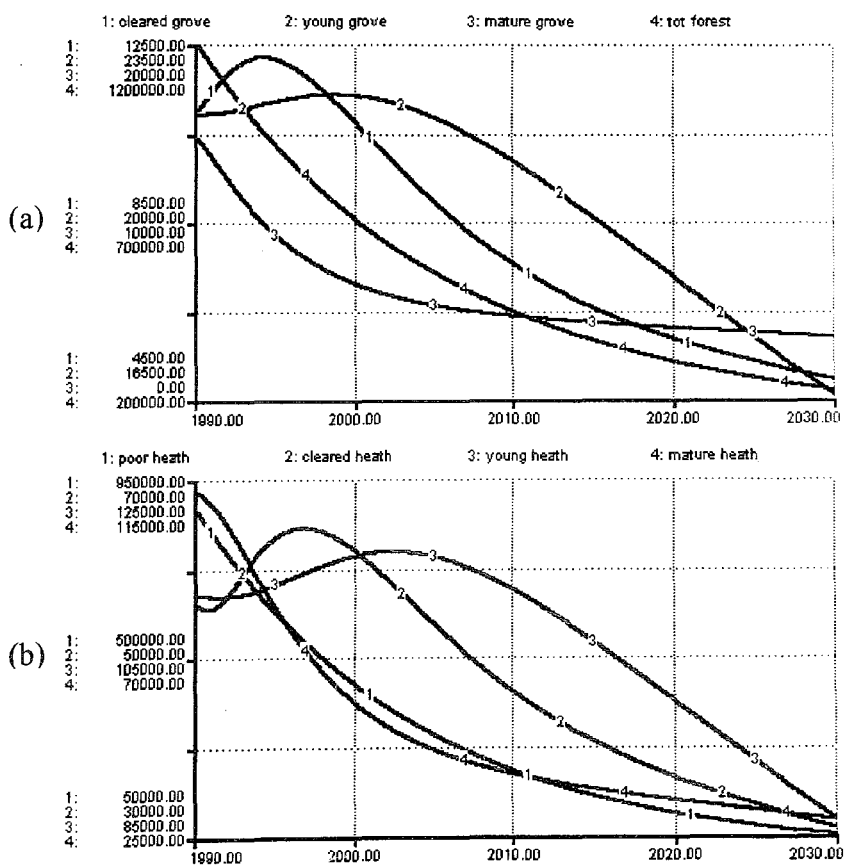


Figure 6.12. Forests under excessive population, excessive industry and no planting conditions.

VI.1.7. Urban Sector Validation and Analysis

In Figure 6.13., sensitivity of GAP urban land (ha) to urban land priority coefficient is illustrated for values, 1, 2, and 4 respectively. The runs confirm our expectations about behavior of urban land. As the priority decreases, rate of urban expansion decreases.

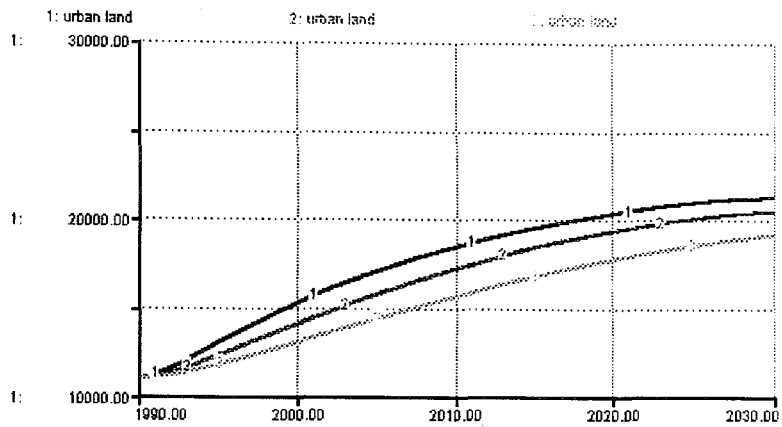


Figure 6.13. Sensitivity of urban land to urban land priority coefficient.

In Figure 6.14., sensitivity of urban jobs (jobs) to the governmental policy variable, desired urban job availability is illustrated for values 0.65, 0.8 and 0.9 respectively. Higher values result in higher public employment and therefore in higher urban job values.

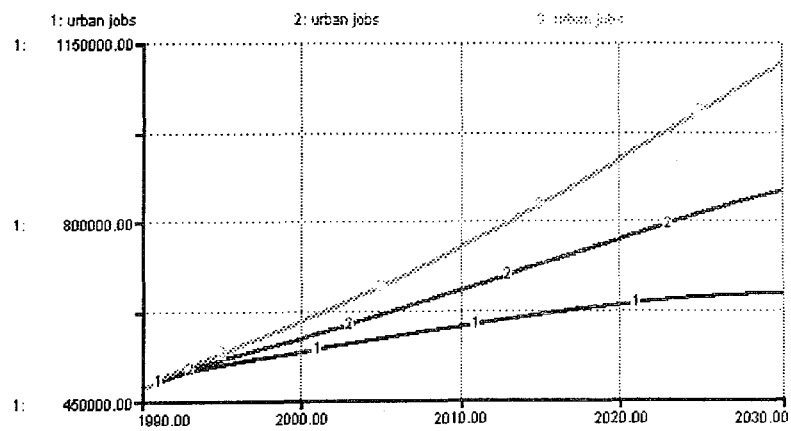


Figure 6.14. Sensitivity of urban jobs to desired job availability parameter.

In Figure 6.15., behavior of GAP urban system under 0 population extreme condition is illustrated. In this run, urban jobs, energy and water requirements gradually decline and urban land stays constant. The response of GAPSIM urban model to this extreme condition is consistent with expected behavior.

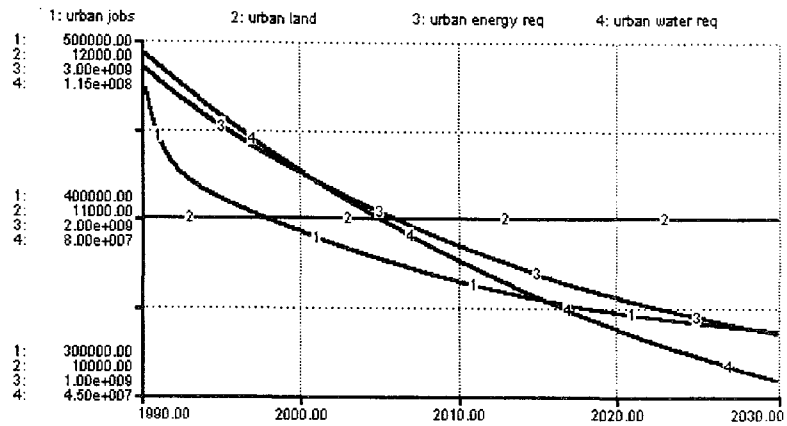


Figure 6.15. Behavior of GAPSIM urban model under 0 population extreme condition

In Figure 6.16., the behavior of urban industries under the extreme condition 0 rawmaterial supply for agroout industry structures and 0 agricultural demand from agroin industry structures is illustrated. In this run, those industry structures in direct relationship with agricultural production (agroout_ind_struct and agroin_ind_struct) immediately decline and those industry structures providing production factors (prod_ind_struct) follow this tendency, confirming a phase relationship with the former industry groups. Consumer industry structures withstand because of increasing population.

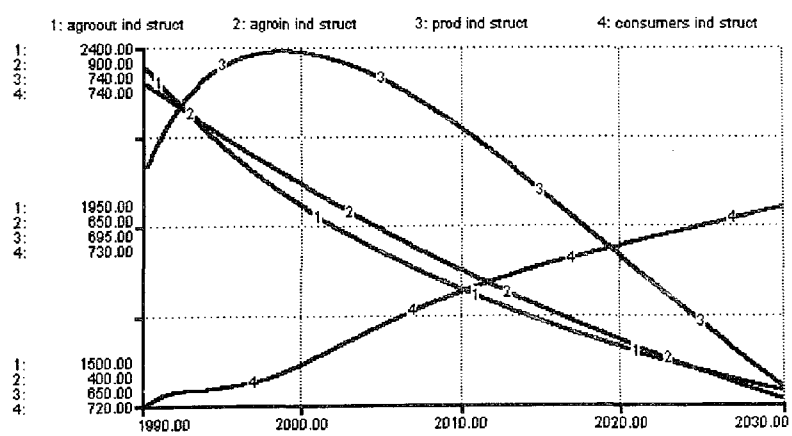


Figure 6.16. Behavior of GAPSIM industry structures under 0 agro-rawmaterial supply and 0 agro-inputs demand.

VI.1.8. Population Sector Validation and Analysis

The last sector to be individually validated is population sector. In this section, three extreme condition tests are applied. In Figure 6.17., isolated run for population sector under "no regional food production" extreme condition is illustrated. Since this extreme condition implies unbearable conditions for the rural community, a sharp collapse in rpopulation (capita) is observed. As job availabilities are constant in the isolated run, urban population (capita) is not significantly affected but at the beginning of the simulation it increases sharply.

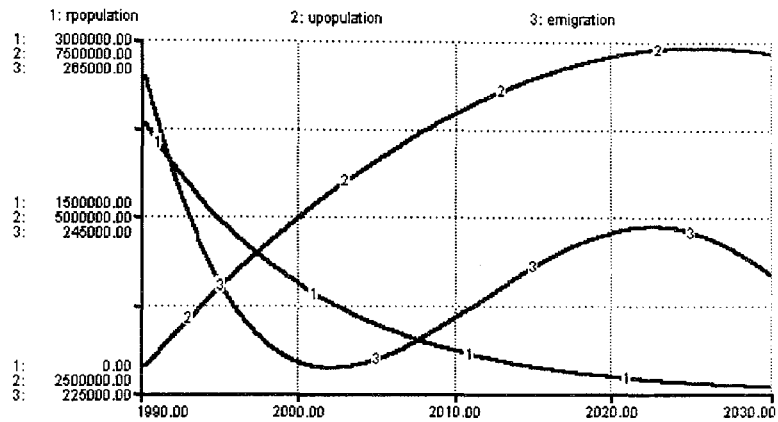


Figure 6.17. Population sector isolated run under "no regional food production" extreme condition.

In Figure 6.18., "no jobs" isolated extreme condition run is demonstrated. In this run, urban population consistently decreases. As attractiveness of urban GAP is destroyed, rate of inregional migration (capita/year) decreases but rural population increases. Also, the very high emigration rate at the beginning of the simulation decreases with decreasing urban population.

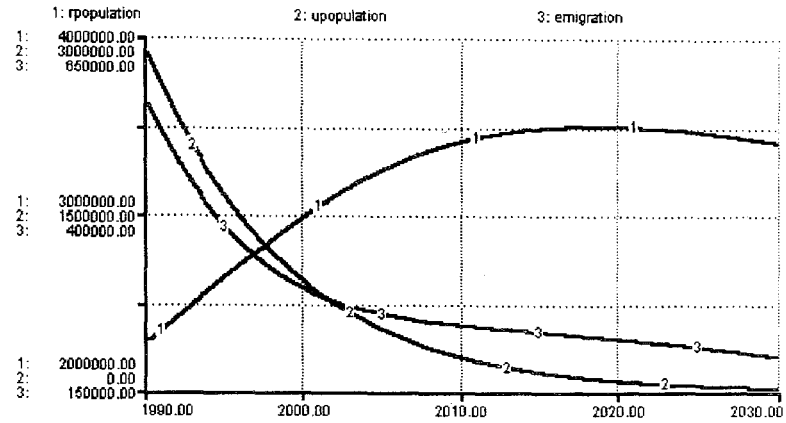


Figure 6.18. Population sector isolated run under "no jobs" extreme condition.

Finally, a third extreme condition, "no jobs outside the region" is tested on population sector. In this isolated run (Figure 6.19.), subsistence ratio (unitless) and job_availability (unitless) are constant, therefore, because of high attractiveness of urban GAP, urban population increases tremendously. At the beginning, emigration rate is very low but soon, it increases with extremely, increasing population.

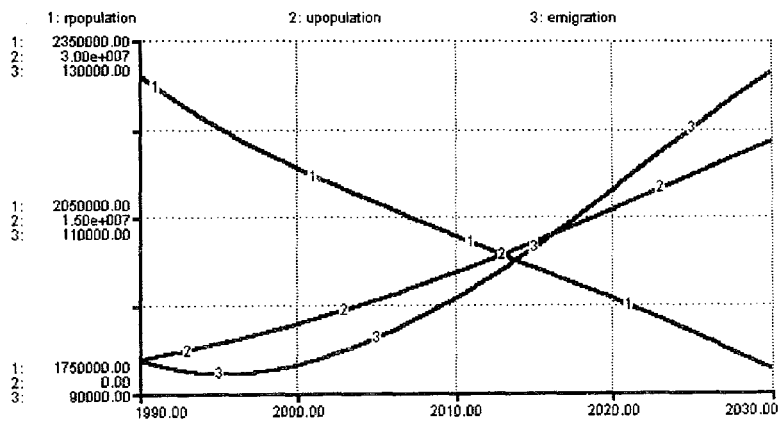


Figure 6.19. Population sector isolated run under "no jobs outside the region" extreme condition.

VI.2. Validation and Analysis of the Model

In this section, several validation tests are performed on the total base runs of the model and in order to improve confidence, model generated behavior is compared with available data and other projections.

VI.2.1. Behavioral Validation of Agricultural Production

In Figures 6.20. through 6.23., regional production of basic agricultural commodities in GAPSIM are compared with data available up to year 1996. In Figure 6.20., model generated behavior for cereal production is compared with cereal production data [84]. The mild increase in cereal production (kg/year) is simulated by the model. The fluctuations in data arise from seasonal differences in average yield, which is ignored in the model.

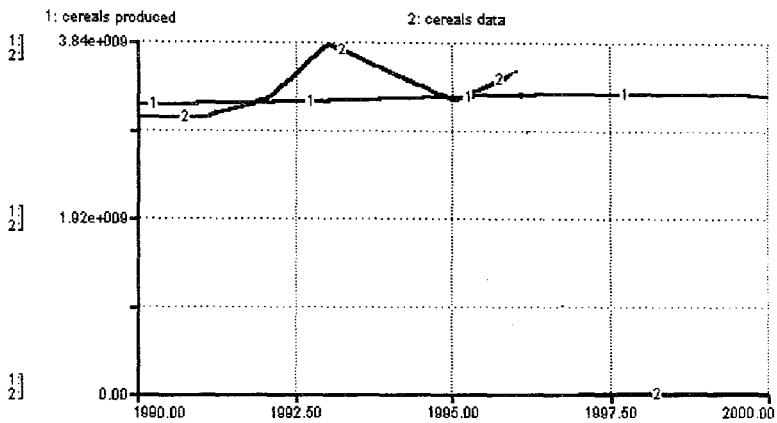


Figure 6.20. Behavior validation for regional cereal production.

In Figure 6.21., the regional pulse production is behaviorally validated [84]. The mild decrease in pulse production (kg/year) in between years 1990 and 1996 is generated by the model.

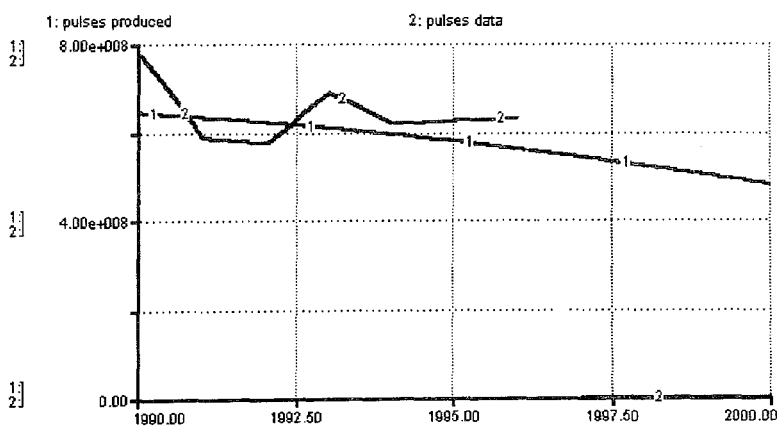


Figure 6.21. Behavior validation for regional pulse production.

In Figure 6.22., behavior validation for regional cotton production is illustrated [84]. Though the model behavior imitates the increase in cotton production till 1996 (kg/year), most of this is due to increased utilization of existing irrigation schemes, which do not belong to GAP projects. From long-term perspective these resources are negligible and are ignored in the model.

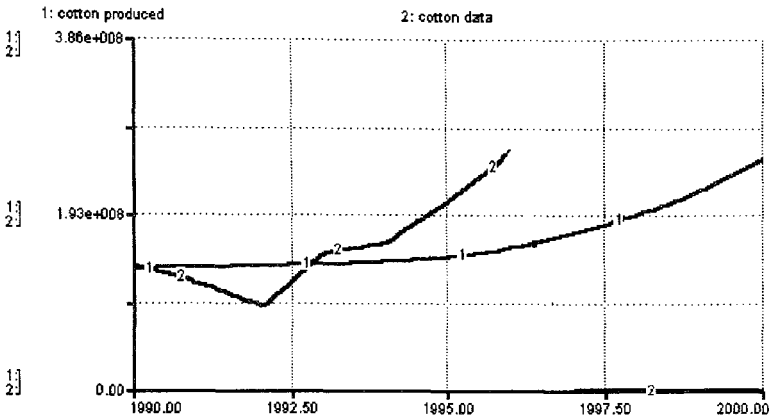


Figure 6.22. Behavior validation for regional cotton production.

In Figure 6.23., livestock quantity (sheep) of the region is simulated and compared with data [84]. Different animals are converted to sheep equivalent according to the same principles used in model construction.

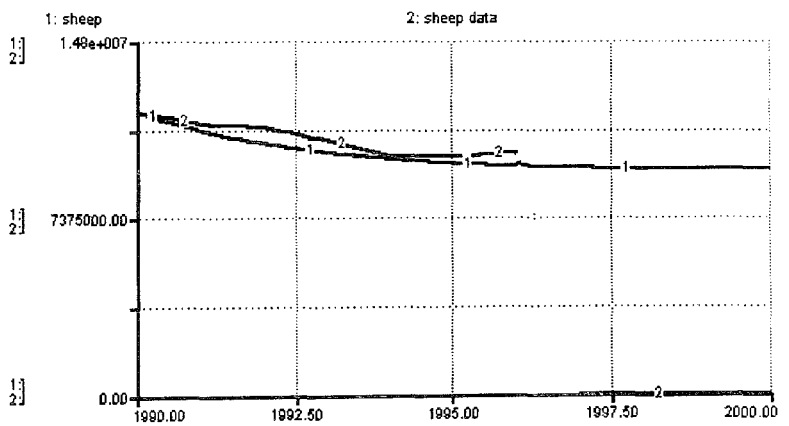


Figure 6.23. Behavior validation for regional livestock quantity.

These four commodities constitute the basic agricultural products, which play an important role in agricultural system of the region, and the model behavior is successful in representing the behavior of these commodities.

VI.2.2. Behavioral Validation of Urban Energy and Land Requirement

In Figure 6.24., urban energy requirement (kWh/year) of the region is compared with data available for years 1990 – 1996 [84]. The urban growth process generated by the model sufficiently represents the increase in regional urban energy requirement.

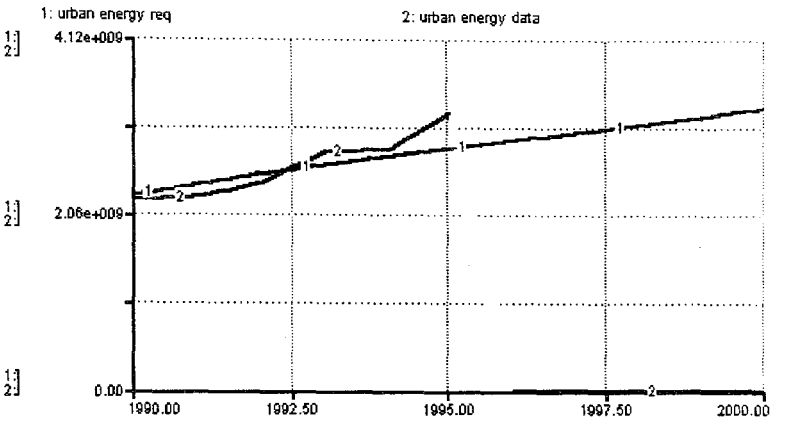


Figure 6.24. Behavior validation for urban energy requirement.

In Figure 6.25., the model-generated increase in urban land (ha) is compared with an other urban land projection till 2005 in GAP Master Plan [83]. The projection of GAPSIM for urban land is moderate when compared to the projections of GAP Master Plan.

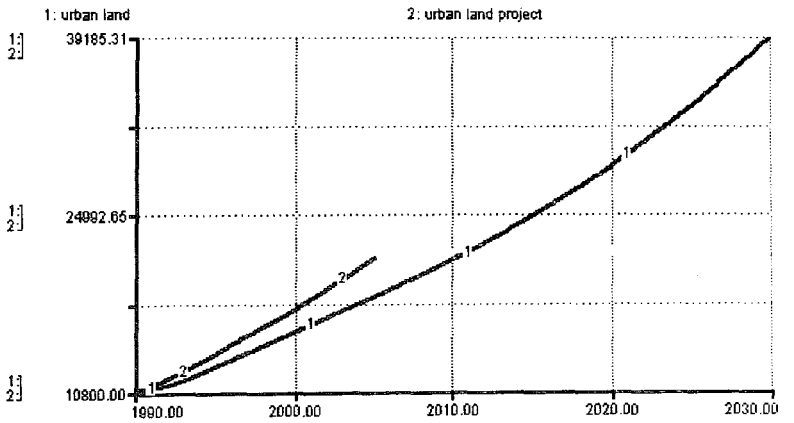


Figure 6.25. Comparison of urban land projection of GAPSIM with that of Master Plan.

VI.2.3. Behavioral Validation of Population

There are several projections about population trends in GAP region. In this section, model generated behavior for rural and urban population parameters (capita) are compared with two projections, first one belonging to GAP Master Plan and the other belonging to the State Institute of Statistics. In Figure 6.26., the behavior of total, rural and urban population parameters are respectively compared with the projection in Master Plan [83].

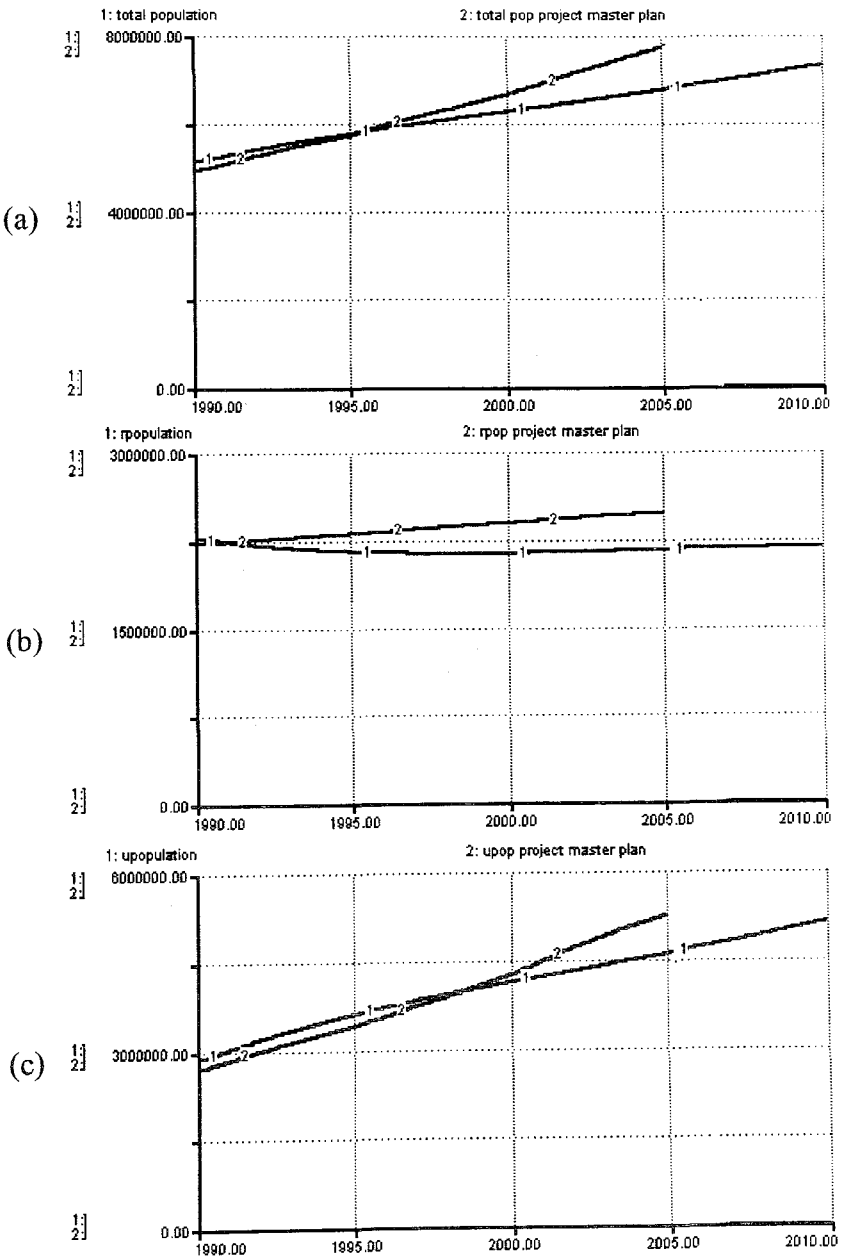


Figure 6.26. Comparison of population parameters with master plan projections.

In the first graph (a) in Figure 6.26., it is observed that, the total population of GAP is overestimated in GAP Master Plan. The reason is that, in Master Plan, the current trends in demography, decreasing fertility and increased emigration rate after 1990 are ignored. These trends were explained in section V.2.12.

In Figure 6.27., this time, model behavior for total population parameter is compared with projections of State Institute of Statistics [100]. This projection is very similar to that in Master Plan, and altough there is a strong emphasis on decreasing fertility in SIS projections, according to the results of 1997 cencius, there is strong evidence that this decrease is underestimated. Also, increased emigration rate after 1990 is ignored.

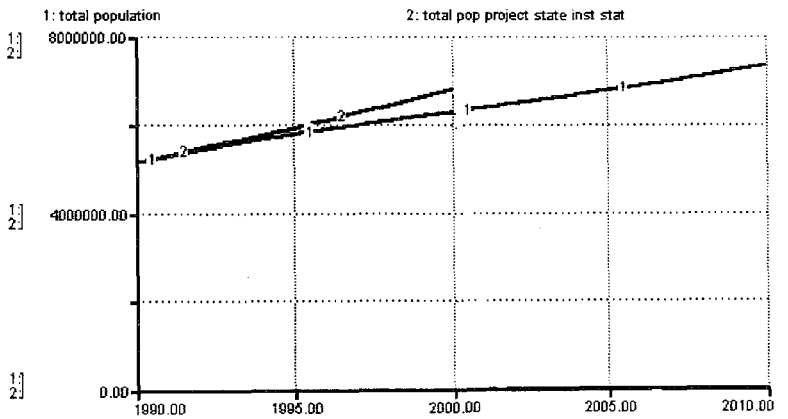


Figure 6.27. Comparison of total population parameter with SIS projection.

In Figure 6.28., comparison of the rural and urban population runs with the results of 1997 census is observed.

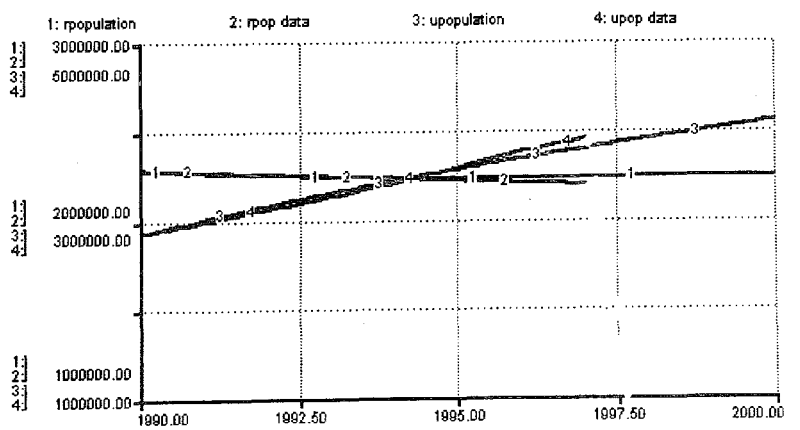


Figure 6.28. Comparison of population parameters with the results of 1997 census.

VII. REFERENCE MODEL BEHAVIOR

In this chapter, with respect to major variables, reference (base) behavior of GAPSIM is demonstrated. The results are aggregated under several groups concerning dynamics of water resources development, land use, land degradation and pollution, agricultural production and population and urban dynamics. The reference behavior depends on the model assumptions explicitly stated in chapter V.

VII.1. Water Resources Development

In this section, dynamics of water resources development is illustrated with respect to irrigated lands (ha), effect of irrigation water availability on yields (irr_mult_normal_yield) and firm energy production (kwh/year). In Figure 7.1., in the first graph (a), the behavior of irrigated lands (ha), lands attributed to cotton monoculture on irrigated fields - COIF (ha), average quantity of irrigation water delivered to COIF (mm/year) and effect of irrigation water availability on yields on COIF – irr_mult_normal_yield [COIF] (unitless) are demonstrated respectively. In this Figure, it is observed that, as irrigated lands and as COIF increase, average quantity of irrigation water delivered to COIF decreases, which results in a decrease in yields. By year 2030, the amount of irrigated lands reach 1.2 million hectares while scarcity in irrigation water may create a decrease in yields by a factor of 0.15. The ultimate value for irrigated lands radically differ from the targeted value (set as 1.7 million hectares) because of a strong bias towards high consumptive use crops in the reference run and inefficiency in water conveyance and farm irrigation.

In the second graph (b), the behavior of the variables, maximum firm energy production (kwh/year), firm energy production (kwh/year), hydropower generation release potential (m^3/year) and irrigation release (m^3/year) are illustrated respectively. Maximum firm energy production is the variable representing energy production capacity of GAP

hydropower plants without any irrigation release. As GAP develops, maximum firm energy production capacity increases but at the same time, releases for irrigation increase and portion of firm basin yield available for hydropower production decrease. This creates the deviation in between maximum and actual firm energy production values. According to the reference run, firm energy production reaches its maximum by year 2015 at about 17.5 billion kwh/year and this correspond to an hydropower release where about 50% of basin yield is utilized for irrigation.

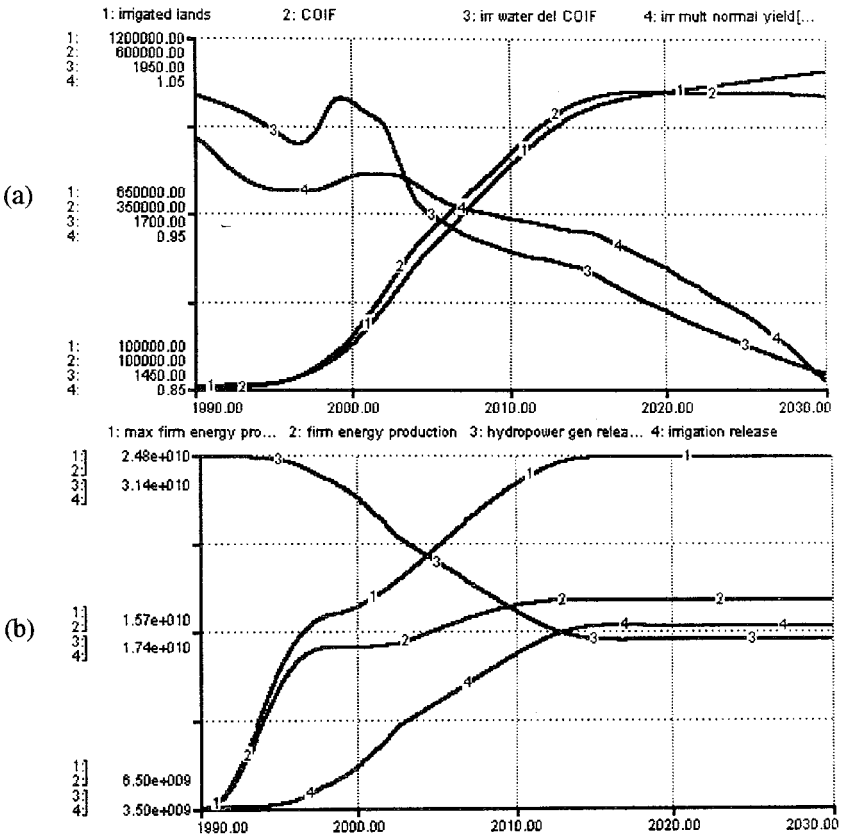


Figure 7.1. Reference behavior for water resources development.

VII.2. Land Use

In this section, model behavior concerning dynamics of land use is demonstrated. First in Figure 7.2., the behavior of arable lands, rangelands, forests, urban land and destroyed rangelands (all in hectares) are illustrated. According to the reference run, arable lands increase by conversion of rangelands and forests and as rural population and rural

population intensity decrease, the rate of conversion decreases and by year 2030, conversion stops. On the other hand, because of overgrazing on rangelands, the destroyed rangeland stock increases significantly. Also, urban lands increase by conversion of arable lands but this does not seem to be significant when respective Figures for arable lands and urban land are compared.

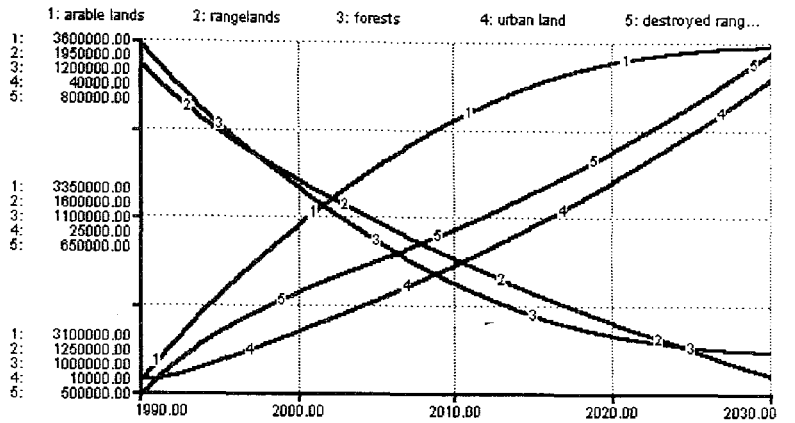


Figure 7.2. Reference behavior for land use.

In Figure 7.3, this time, dynamics of change within the arable lands is illustrated. In the firs graph (a), the behavior of rainfed fields CERF (cereals monoculture on rainfed fields), CEPRF (cereals pulses rotation on rainfed fields) and RFWG (rainfed wine-garden) and in the second graph (b), the behavior of irrigated fields COIF (cotton monoculture on irrigated fields), COSIF (cotton – summer crops rotation), CESIF (cereals-summer crops rotation on irrigated fields), CCSPIF (cereals-cotton-pulses-summer crops rotation on irrigated fields) and IRWG (irrigated wine-garden) all in hectares are shown. According to the reference run, as GAP develops, CEPRF decrease significantly and CERF increase after a period of stagnation between 2000 and 2015. A portion of RFWG are converted to IRWG. On the irrigated fields, there is a very strong bias towards COIF and COSIF which creates high diversion requirements and water scarcity in middle term as illustrated on Figure 7.1. Because the profitability of certain crops and model assumptions related with marketing safety, local consumption advantage and know–how requirements of certain crops and farm systems, CESIF do not increase significantly and CCSPIF can not withstand. The intensification of cotton and summer crops production and elimination of cereals and pulses production on irrigated fields has adverse affects on land degradation and pollution parameters related with salinization, pesticides, fertilizers and soil erosion.

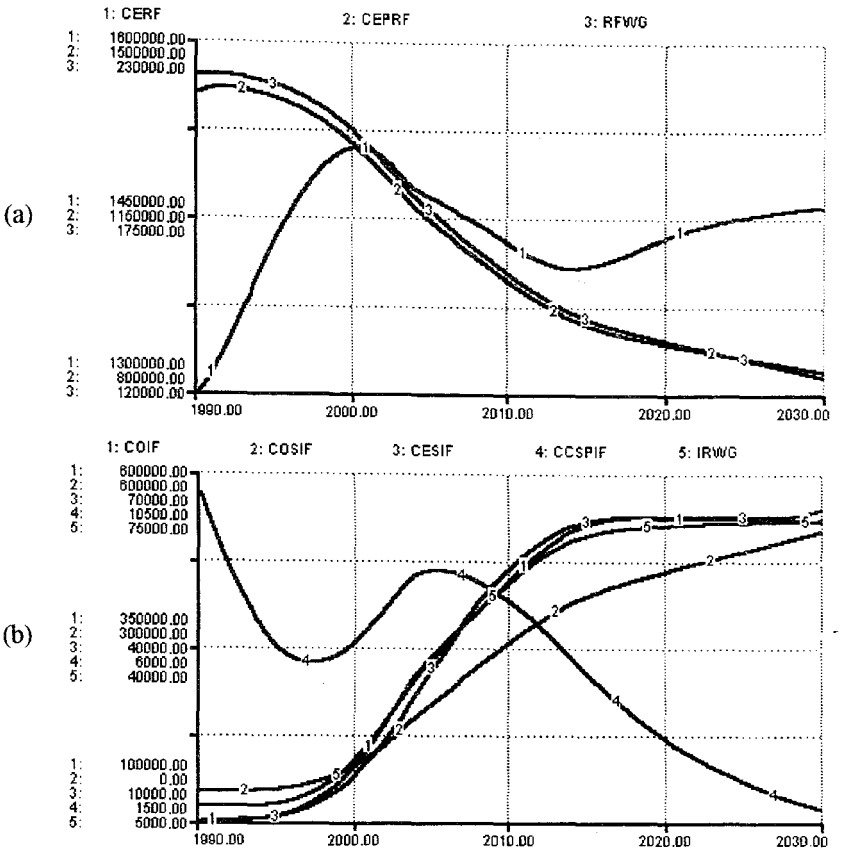


Figure 7.3. Reference behavior of arable lands.

In Figure 7.4., the behavior of aggregated rangeland groups is illustrated. Here, it can be observed that, rich rangelands are gradually converted to poor rangelands and poor rangelands are converted to destroyed rangelands (all in hectares). The resulting behavior is decreasing rich and poor rangelands (ha) and a significant increase in destroyed rangelands (ha) because of overgrazing.

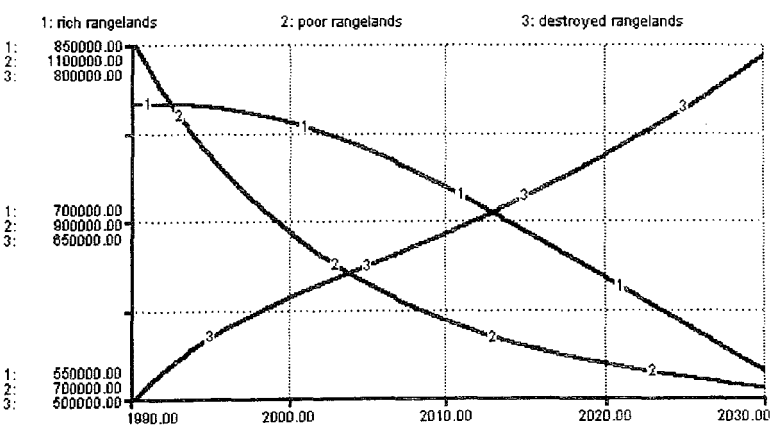


Figure 7.4. Reference behavior of rangelands.

In Figure 7.5., the behavior of variables concerning forestlands (all in hectares) is illustrated. In the first graph (a), the behavior of grove lands (forests for timber supply) and in the second graph (b), the behavior of heath lands (forests for firewood supply) are shown. The reference behavior is based on poor heathland conversion to young grove and young heath lands according to the governmental policy fixed by the variables desired_grove_and, desired_heath_land, grove_planting_fract and heath_planting_fract described in government sector description in section V.2.14.

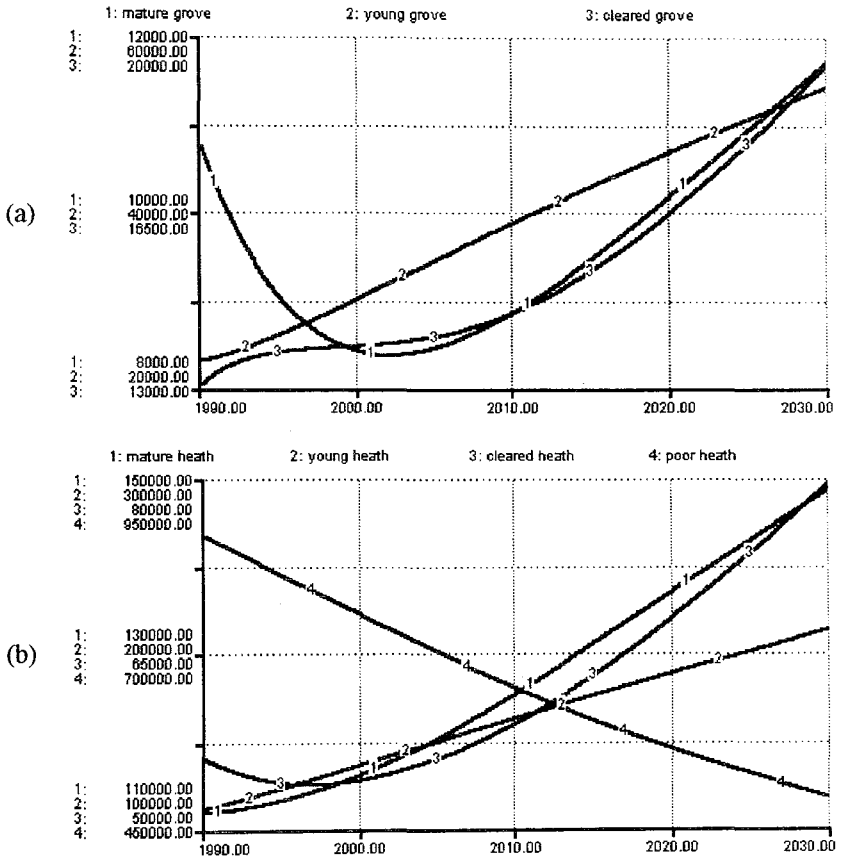


Figure 7.5. Reference behavior of forest lands.

VII.3. Land Degradation and Pollution

In this section, reference model behavior for salinization, erosion, and pesticides and fertilizers consumption rates are illustrated. In Figure 7.6., the average salinization

profile calculated for GAP arable lands (salt_conc_root_zone in mg/l) is observed. According to this run, by year 2010, the average salt concentration at root zone is about 3000 mg/l, which is a seriously harmful concentration inhibiting plant growth especially for those crops such as pulses, vegetables and fruits.

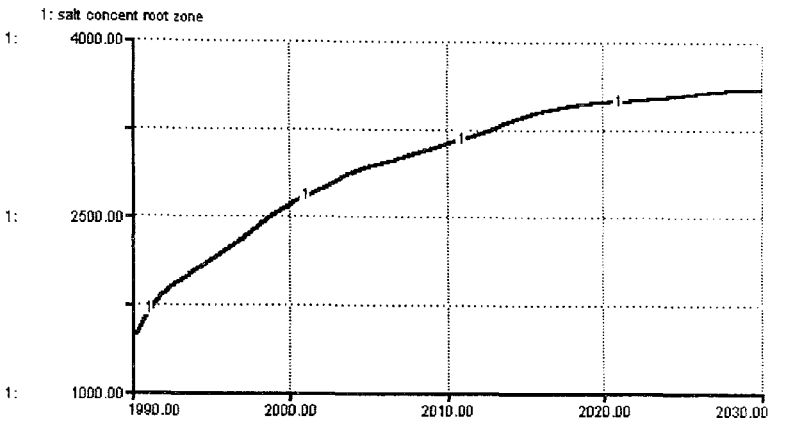


Figure 7.6. Reference behavior for salt concentration at root zone.

In Figure 7.7., soil erosion rates for several arable lands, forest and rangeland groups are demonstrated. In each graph in Figure 7.7., the variable, remaining_soil_ratio (unitless) corresponds to the portion of upper soil layer in terms of depth that is not eroded. In the first graph (a), erosion rates for rainfed fields, rainfed wine-garden, irrigated fields and irrigated wine-garden are simulated respectively. In the second graph (b), soil erosion for heathlands, grovelands and rangelands are simulated. It is observed that, according to the formulation suggested by universal soil loss equation and parameters provided for GAP region, since slope in arable lands and rainfall erosivity is low, erosion rate is significant only for the rangelands, where on the average, 10% of top soil is lost in 40 years simulation time. In these graphs, one can also observe that, rate of soil erosion increases by time, such that, the behavior of the variable remaining_soil_ratio follows an exponential collapse because of the feedback structure explained in section V.2.10.

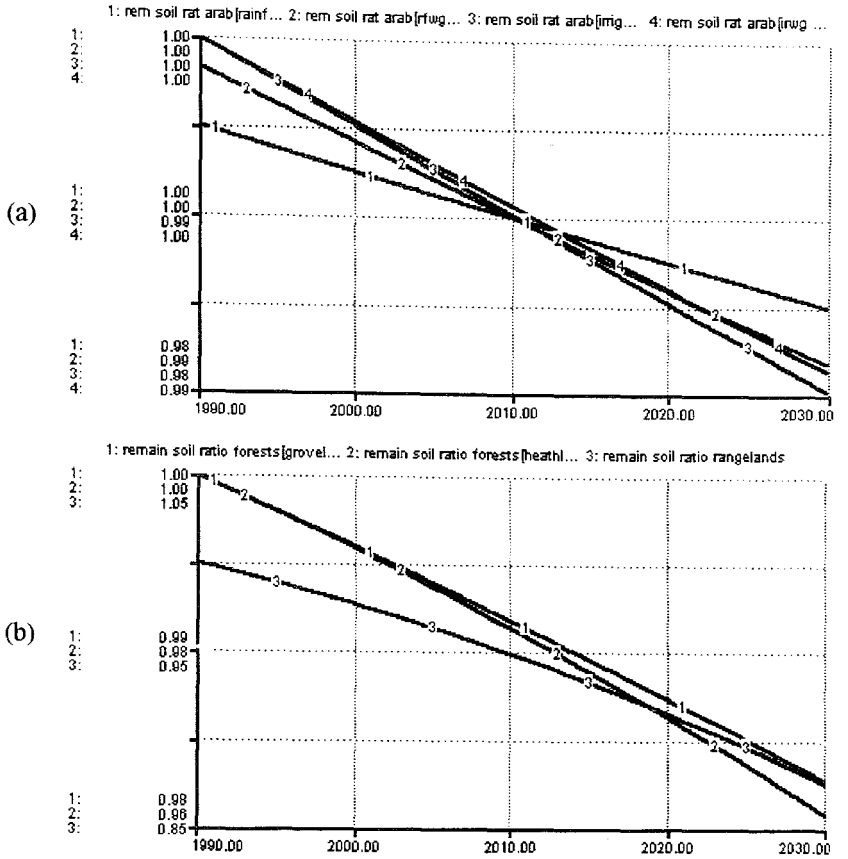


Figure 7.7. Reference behavior for soil erosion.

In Figure 7.8., reference behavior for pesticide consumption rates (kg/ha/year) is illustrated. In the first graph (a), reference behavior for pesticides consumption rates in terms of effective material (kg/ha/year) for three irrigated farm systems, COIF, COSIF and CCSPIF are shown. The behavior for COIF corresponds to the highest pesticides requirement and that for CCSPIF corresponds to the lowest pesticides requirement. In the second graph (b), this time a more aggregate variable, average pesticide consumption rate on irrigated fields (kg/ha/year) in terms of effective material is illustrated. According to the reference run, it is observed that, due to the increased staying times of the fields COIF and COSIF, between years 2000 and 2010, average pesticide consumption rate increases and then decreases by decreasing staying times. Increased staying times imply increased pests and farmers tend to apply high pesticide application which in turn elevates pests resistance development according to the feedback structure explained in section V.2.7. Note that, increased second cropping also effects consumption rates of agricultural inputs. For

example, increased pesticide consumption for CCSPIF on Figure 7.8. is because of increased second cropping percentages.

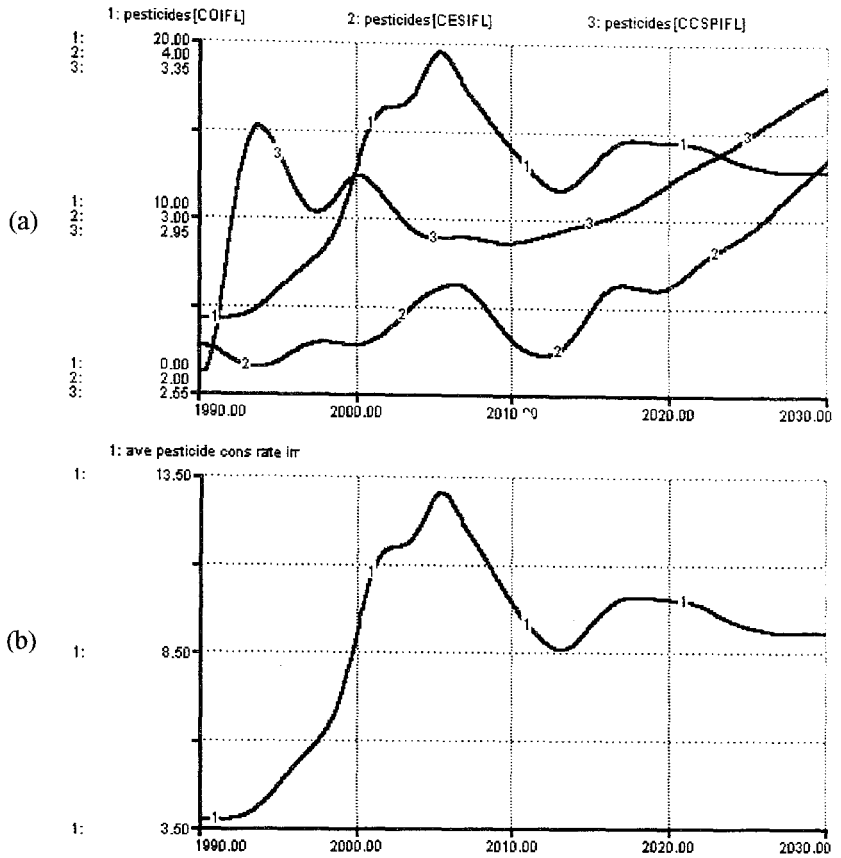


Figure 7.8. Reference behavior of pesticide consumption rates.

In Figure 7.9., reference behavior for average nitrogen consumption rate (kg/ha/year) in terms of mineral nitrogen N, average leaching portion of this quantity (kg/ha/year) in terms of N and average phosphate consumption rate (kg/ha/year) in terms of P_2O_5 on GAP irrigated fields are demonstrated. It is observed that, in response to decreasing fertility, fertilizer application rates and leaching nitrogen increase throughout the simulation horizon.

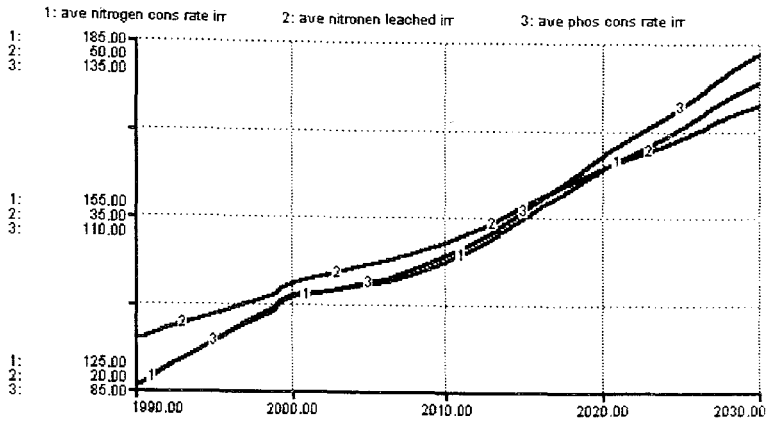


Figure 7.9. Reference behavior for fertilizer consumption and leaching nitrogen rates.

VII.4. Agricultural Production

In this section reference behavior for yield and supply of eight agricultural commodities represented in GAPSIM are illustrated. Supply variables for individual agricultural products represent the marketed quantities, i.e., quantity calculated after local consumption is dropped (kg/year). Yield variables are calculated as an outcome of multiple effects such as fallow, water availability, salinization, erosion, fertilizers and pesticides utilization (kg/ha/year). Yield calculations were described in detail in sections V.2.1, V.2.2. and V.2.3. For all products, yields on different farm systems are averaged separately for rainfed and irrigated fields in order to get measures representing yields on GAP fields.

In Figure 5.10., in the first graph (a), reference run for cereals supply (kg/year), cereals yield on rainfed fields (kg/ha/year), cereals yield on irrigated fields (kg/ha/year) and avarage cereals yield on GAP fields are illustrated. In this run, the moderate increase in yield on rainfed fields is due to the effect of increased fallow practices. Decreasing rural population and decreasing rural population intensity on rainfed fields imply increased fallow percentages. On the other hand, the increase in yield on irrigated fields is because of increased fertilizer consumption rates illustrated on Figure 7.9. In the second graph (b), similar variables with the same units are simulated for pulses. In this graph, pulses supply decrease because of decreasing pulse cultivation areas and yield on rainfed fields increase

because of the same reason described for cereals. But, pulse yield on irrigated fields also decrease, as increased fertilizer application can not recover initial yields.

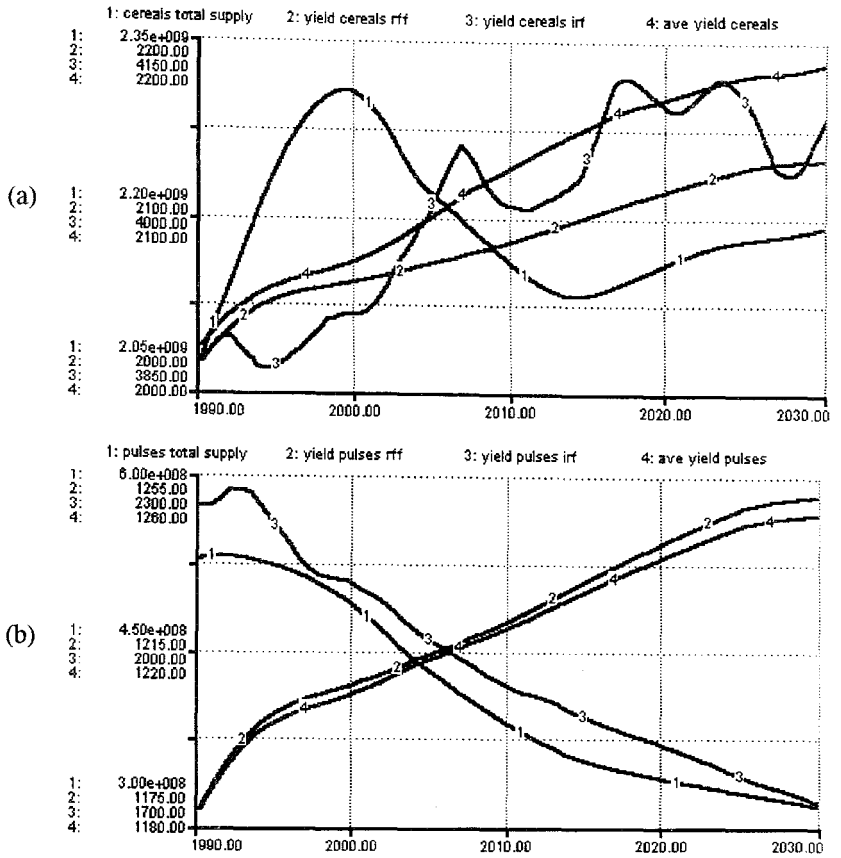


Figure 7.10. Reference behavior of cereals and pulses supply and yield.

In Figure 7.11., total supply (kg/year) and yield (kg/ha/year) of cotton, oil crops, summer cereals and vegetables are illustrated. In these graphs, as supply quantities of all these crops increase with increased irrigated fields illustrated in Figure 7.3., yields decline, seriously especially for oil crops, summer cereals and vegetables although fertilizer application rates increase. This decline depends mainly on increased soil salinity.

In Figure 7.12., similar variables are simulated for fruits. In this figure, fruits supply (kg/year) and yields (kg/ha/year) both for rainfed and irrigated wine-garden are illustrated. According to the reference behavior, there exists a mild decline in yield on rainfed wine-garden due to soil erosion. Decline in yield on irrigated wine-garden is

greater as soil salinization process is active for these lands. Again, fertilizer application rates increase for fruits in order to recover initial yields as shown in Figure 7.9.

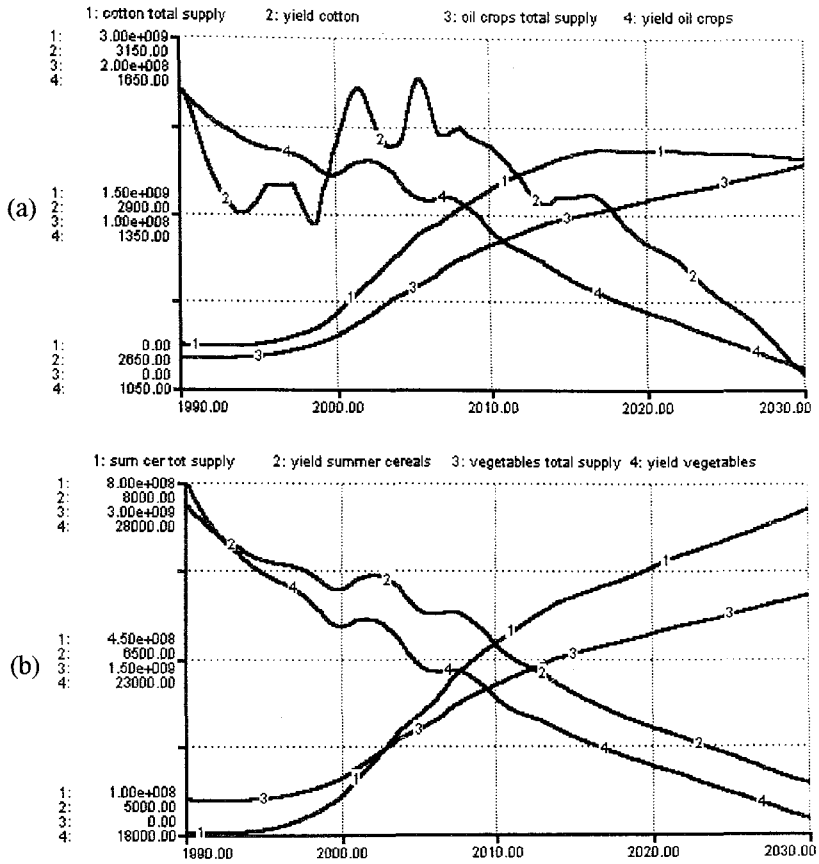


Figure 7.11. Reference behavior of cotton, oil crops, summer cereals and vegetables supply and yields.

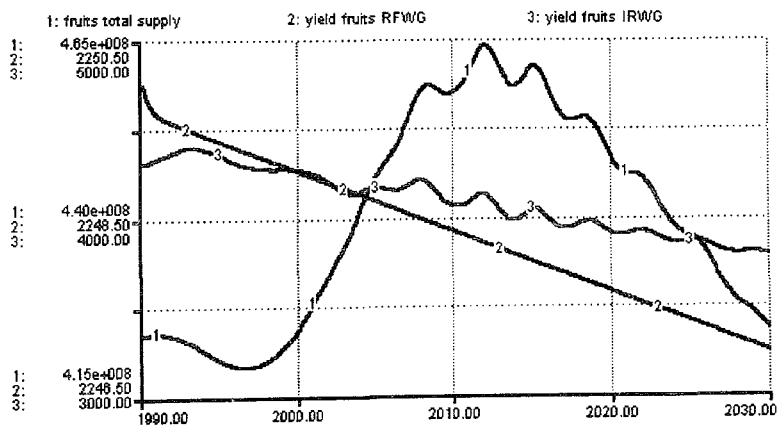


Figure 7.12. Reference behavior of fruits supply and yield.

The last behavior illustrated in this section is for livestock quantities. In Figure 7.13., the variables sheep fed on farmlands, sheep fed on rangelands and their total are simulated (all in sheep). According to this reference run, although there is a mild increase in sheep on farmlands, total sheep declines seriously as sheep on rangelands decrease. This decline depends on rangelands destruction and the improvement in animal husbandry on farmlands can not compensate the loss in total sheep.

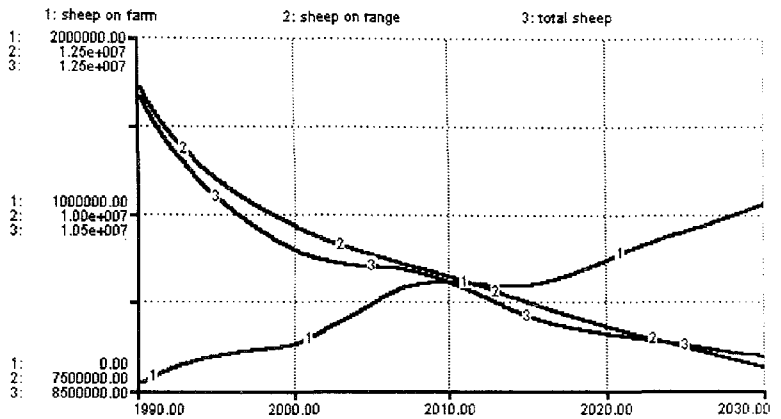


Figure 7.13. Reference behavior of sheep on farmlands and rangelands.

VII.5. Population and Urbanization

In this section, reference behaviors concerning population dynamics and urbanization are illustrated. In Figure 7.14., variables concerning urbanization, urban jobs (jobs), urban energy requirement (kwh/year) and urban water requirement (m^3/year) are simulated. According to the base run, by year 2030, 1.25 million jobs are created, and a four times increase in energy and water requirements is observed.

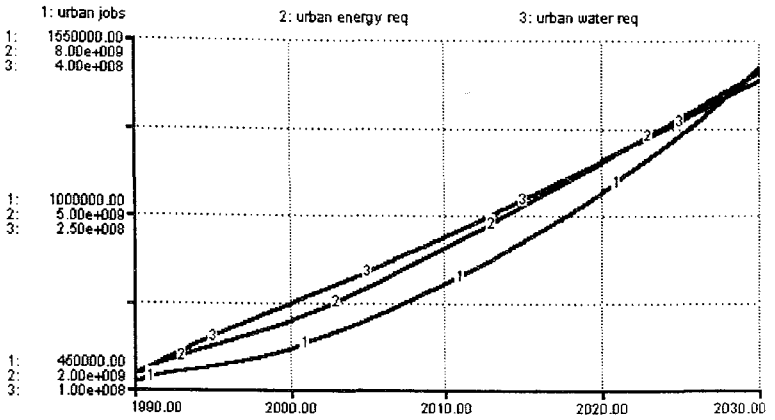
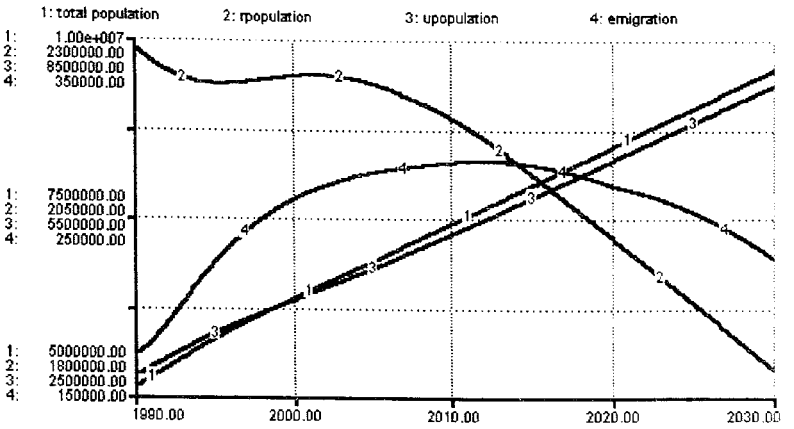


Figure 7.14. Reference behavior of urban jobs, energy and water requirements.

The last Figure in this chapter concerns population dynamics. In Figure 7.15., in the first graph (a), the reference behavior of total population, rural population, urban population (all in capita) and regional emigration rate (capita/year) are illustrated. Based on the model assumption about decreasing regional net birth rates explicitly stated in section V.2.12, if high rural emigration to the urban GAP and to outside the region observed between the years 1990 and 1997 sustains, GAP rural population will continue decreasing. But, still, total population of GAP will reach 10 million, as urban population will increase. Accordingly, emigration rate will increase till year 2010 where it reaches 280000 (capita/year), and then decline. In the second graph (b), behavior of the variables rural food availability (unitless) and urban job availability (unitless), which drive population dynamics, are demonstrated. By decreasing rural population, availability of food (ratio of cereals pulses and summer cereals production to rural consumption of these products) will increase in rural GAP and by year 2000, job availability in urban GAP (ratio of urban jobs to the potential urban labor) will begin to increase. But, according to the base run, the improvement in underemployment rate is mild where it reaches from about 50% by year 2000 to about 30% by year 2030.

(a)



(b)

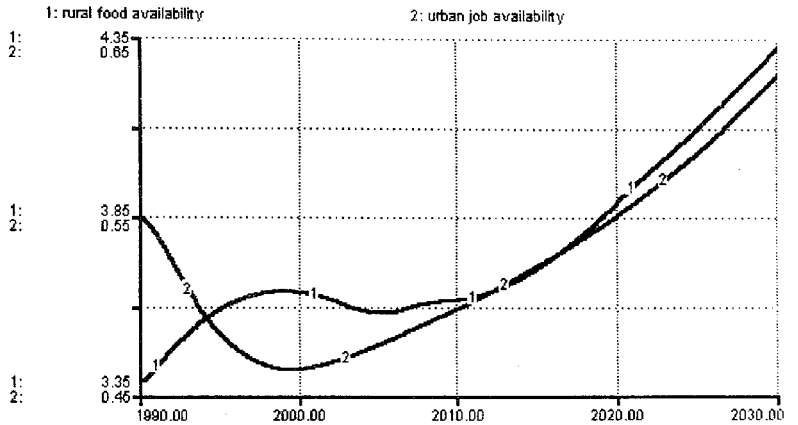


Figure 7.15. Reference behavior of population, food and job availability.

VIII. SCENARIO AND POLICY ANALYSIS

In this chapter, several scenario and policy analyses are performed on GAPSIM and important modifications on the reference run are discussed in detail in order to arrive at a better understanding of the system. First, several sensitivity and scenario analyses, then policy analysis are illustrated.

VIII. 1. Sensitivity and Scenario Analysis

In this section, discussion of the scenario analyses related to land use, agricultural pollution, urbanization and population are presented. In the first section, system performance is analyzed with respect to changing crop priority and farm constants affecting arable land use dynamics.

VIII.1.1. Scenario Analysis Related to Land Use

In this section, two scenario analyses are performed on land use dynamics. First, parameters affecting arable land use are modified to observe changing system performance and then, assumptions determining rate of transformation from rainfed to irrigated lands is altered.

VIII.1.1.1. Traditional Attitudes in Crop Preference Change after Year 2000

In GAPSIM, land flows in between arable lands were formulated with respect to three basic criteria. These were relative profitability of different farm practices, relative advantage of dominant crops in terms of hectares that they occupy (majority effect), local consumption and marketing advantage of certain crops and know-how requirement of

certain farm practices. In the base run, farm constants representing know-how requirements were set as 1 for single farm, 1.5 for two farm and 2 for multiple farm systems and wine–garden according to the order of decreasing advantage. In "crop preference change after year 2000" scenario analysis, between 2000 and 2010, all farm constants gradually become equal to the single farm constant and majority effect is omitted. This scenario implies that, after year 2000, as GAP develops, traditional attitudes of farmers for crop preference and farm practices will change with changing technology and with effective farm extension practices.

According to this scenario, there is not any modification in firm energy production (kWh/year) and irrigation release (m^3/year) since the behavior of these variables are determined by GAP construction rate and irrigation priority. But, as land use and intensity of certain crops are modified and intensity of high consumptive-use crop cotton has decreased, irrigated lands (ha) increase considerably. Also, irrigation water availability on individual farms is improved. The modified behavior of those variables related to water resources development are illustrated in Figure 8.1.

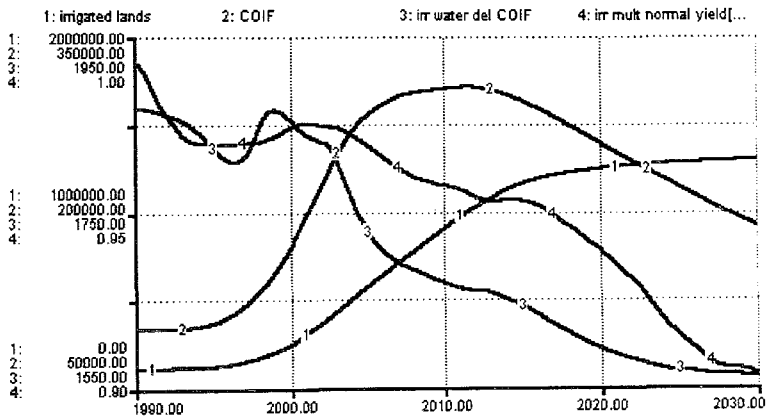


Figure 8.1. Irrigated lands and water availability in "crop preference change after year 2000" scenario.

In Figure 8.2., arable land use dynamics is shown (all in hectares). When this modified behavior is compared with the base run (see Figure 7.1.), on rainfed lands, cereals-pulses rotation and wine-garden increase, and on irrigated lands, while cotton monoculture decreases significantly, all other farms increase. Especially, fields representing cotton-summer crops rotation reach about 700 thousand hectares.

Since, increase in the most pesticide consuming farm system COIF (cotton monoculture on irrigated fields) is controlled in this run, and also, as the average residence time for this land is diminished, average pesticide consumption rate for irrigated fields (kg/ha/year) is significantly decreased (Figure 8.3.). But still, there is peak in this parameter between 2000 and 2010 because, the initial increase in COIF is similar with that in the base run. According to this scenario, as cultivation of other summer crops increase, pesticide consumption rates and average value for leaching mineral nitrogen on irrigated fields (kg/ha/year) slightly increase, though it follows the similar dynamics with the base run.

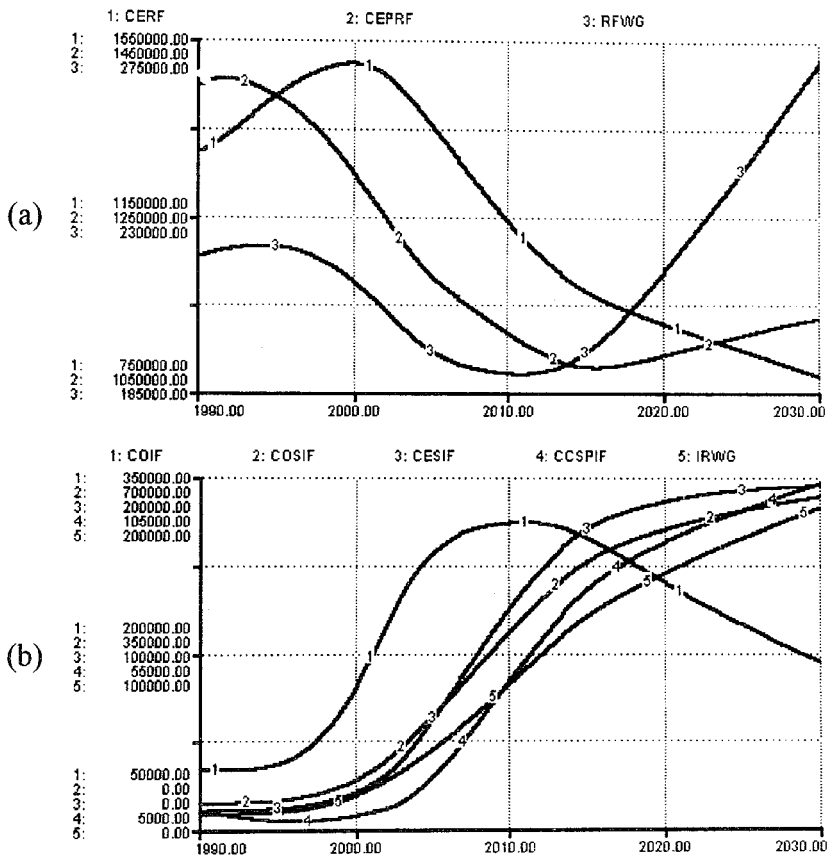


Figure 8.2. Arable land use in "crop preference change after year 2000" scenario.

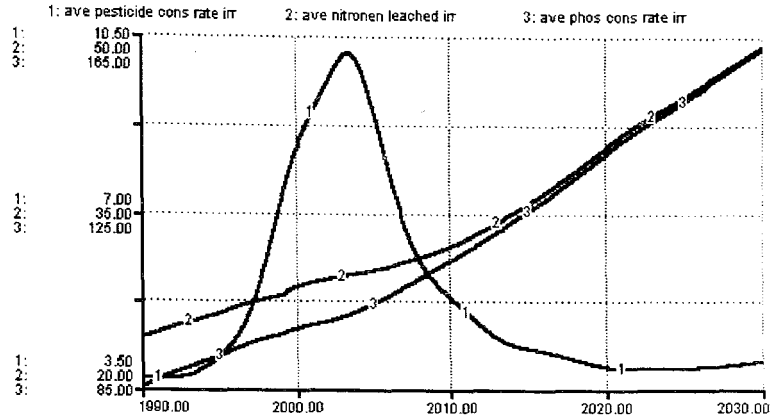


Figure 8.3. Pesticides and fertilizers consumption in "crop preference change after year 2000" scenario.

In this run, of course, supply values for agricultural products change significantly, but their corresponding average yields are not modified. In Figure 8.4, total supply values (kg/year) are illustrated. According to these results, total supply of cereals and cotton decrease and total supply of pulses, oil crops, summer cereals, vegetables and fruits increase when compared with the base run.

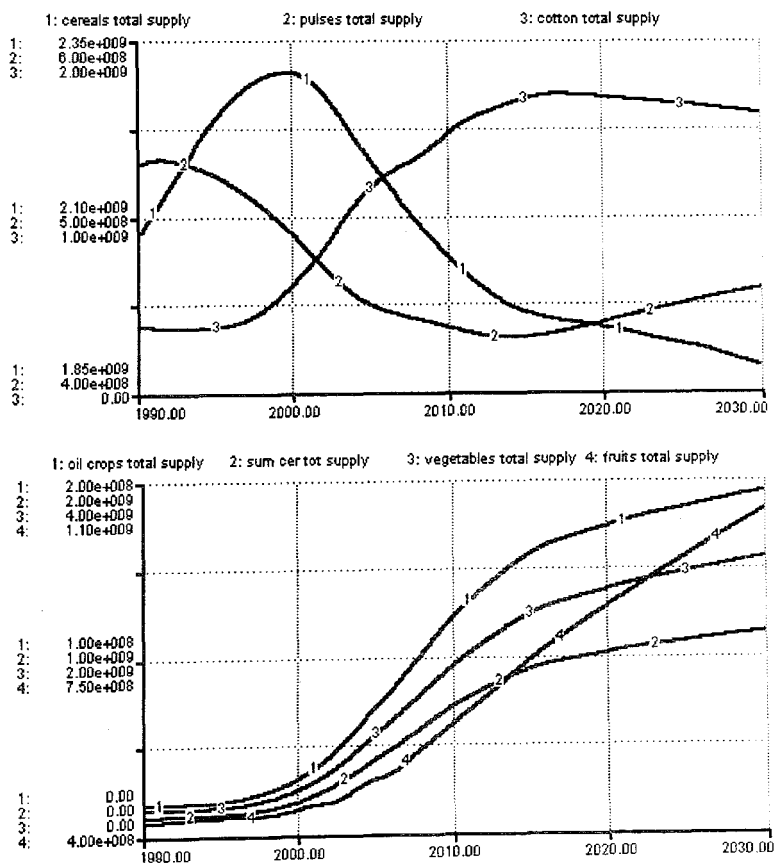


Figure 8.4. Agricultural supply in "crop preference change after year 2000" scenario.

VIII.1.1.2. Rapid Land Transformation

The "rapid land transformation" scenario implies that, farmers are more willing to transform their rainfed lands whenever irrigation release is available and therefore, more hectares are irrigated with a given quantity of irrigation release. Again, in this scenario, the behavior related to total irrigation release and firm energy production does not change. Modified behavior for irrigated lands (ha), and irrigation water availability (unitless) on individual lands, as for example for COIF, is illustrated in Figure 8.5. According to this run, while irrigation water availability on COIF decreases and results in yield loss of about 30%, total irrigated lands increase considerably and reach to about 1.6 million hectares.

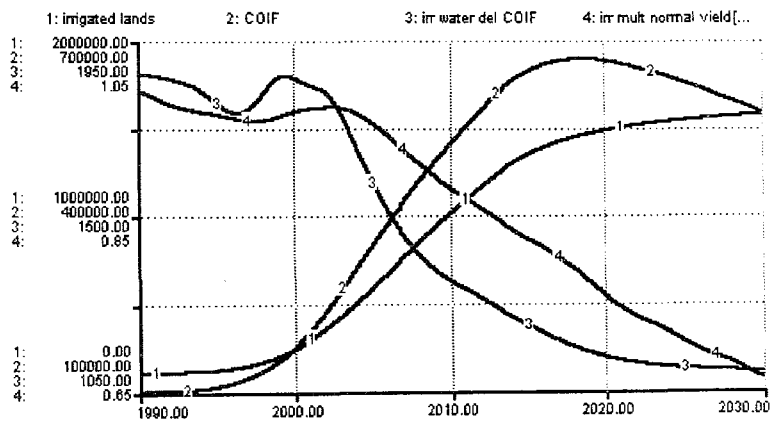


Figure 8.5. Irrigated lands and water availability in "rapid land transformation" scenario.

This scenario has significant effect on arable land use dynamics, because, as availability of irrigation release per hectare decreases, scarcity of irrigation water affects more the highest consumptive use crops such as cotton and the intensity of lowest consumptive use crops such as cereals, summer cereals, oil crops and pulses on irrigated fields increase. The resulting behavior is illustrated on Figure 8.6.

Changing arable land use creates modified behavior in soil root zone salt concentration (mg/l) and average pesticide consumption rate (kg/ha/year). In Figure 8.7, it is observed that, with changing crop pattern, as average irrigation water applied on irrigated fields decrease, average salt concentration profile is decreased with respect to the base run. Also, as cotton monoculture and its average residence time has been altered, average pesticide consumption rate begins to decrease with year 2010.

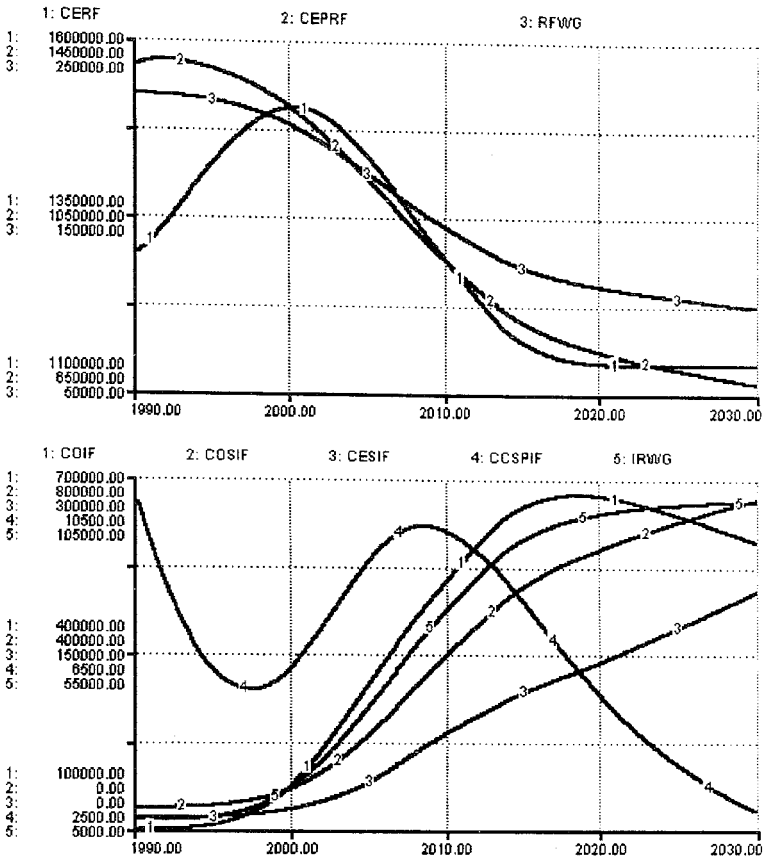


Figure 8.6. Arable land use in "rapid land transformation" scenario.

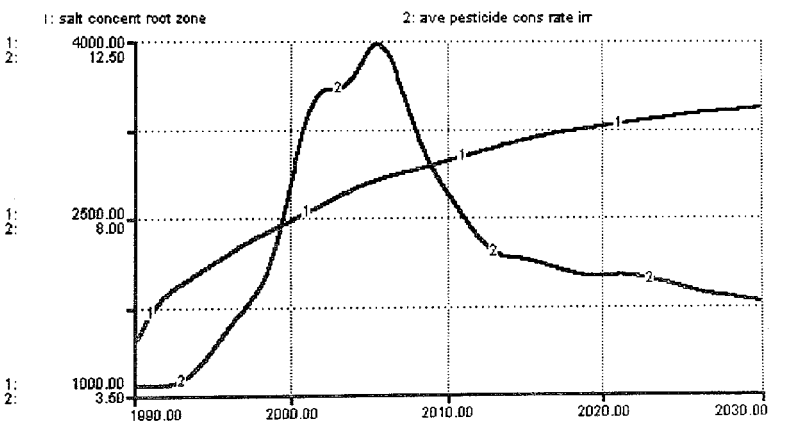


Figure 8.7. Land degradation and pollution in "rapid land transformation" scenario.

"Rapid land transformation" scenario modifies supply and yield of agricultural products. Significant modifications are summarized in Figure 8.8. Cotton yield (kg/ha/year) is considerably affected by water scarcity, yield of vegetables and fruits are slightly affected but cereals, pulses, oil crops and summer cereals yields are not affected since these are relatively low consumptive use crops. When total supply are compared with the base run, it is observed that, there is not significant change for cereals and cotton, pulses total supply decrease as more lands are transformed to irrigated fields and supply for oil crops, summer cereals, vegetables and fruits increase.

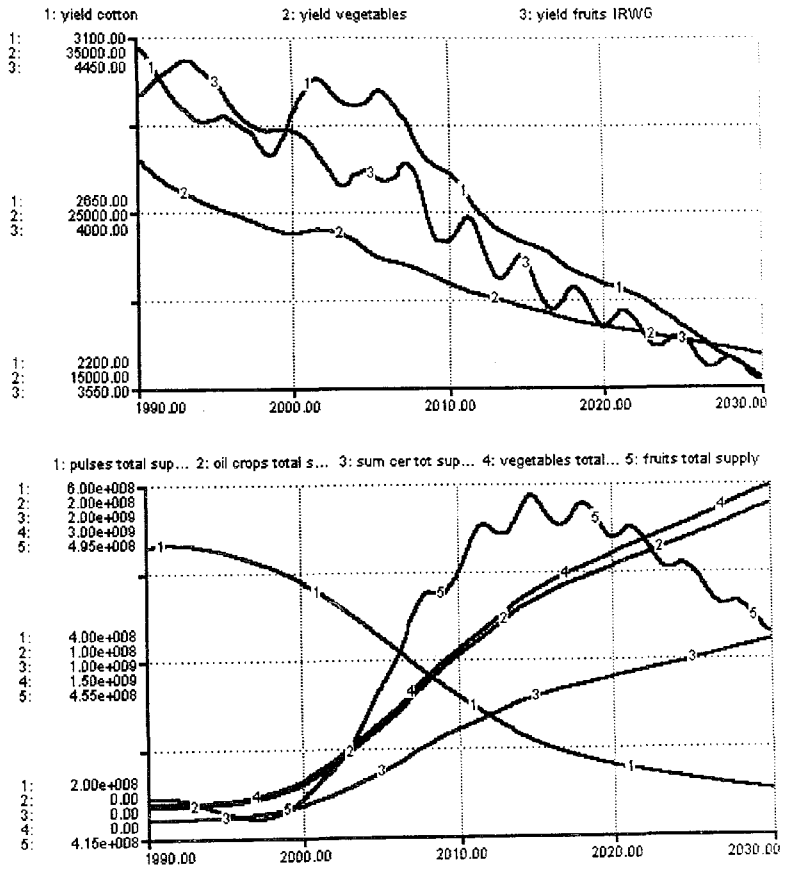


Figure 8.8. Agricultural production and yields in "rapid land transformation" scenario.

VIII.1.2. Scenario Analysis Related to Agricultural Pollution

In this section model sensitivity to changing pest resistance building characteristics and changing fertilizer application rates are analyzed.

VIII.1.2.1 High Pest Resistance Building

In the first analysis of this section, variables representing pest resistance building, pesticides_eff_pest_resist and farm_stay_eff_pest_density in pesticides sector in section V.2.7. is modified to increase pest resistance building with respect to increased pesticide consumption rates and increased average farm residence times. This scenario implies poor pest management strategy, such that, the chemicals introduced to the market stimulate pest resistance building and their field applications are not successfully monitored.

The altered behavior for average pesticide consumption rates for COIF (cotton monoculture on irrigated fields), COSIF (cotton summer crops rotation on irrigated fields), CCSPIF (cotton, cereals, summer crops, pulses rotation on irrigated fields) and the average for GAP irrigated fields according to this scenario is illustrated in Figure 8.9. In this run, pesticides burden on COIF and COSIF increase while average pesticides consumption on CCSPIF is not affected since intensive crop rotation on these fields avoid pest resistance building. The average pesticide consumption on GAP irrigated fields is increased in this run (compare with Figure 7.8 - b).

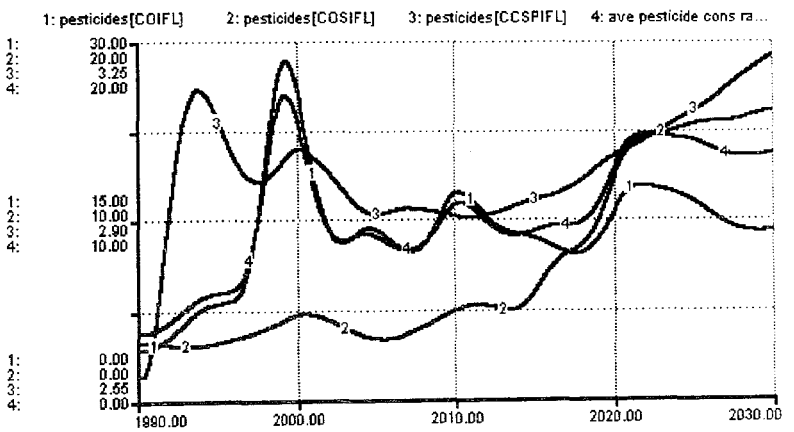


Figure 8.9. Average pesticide consumption rates in "high pest resistance building" scenario.

Increased pesticide application especially on COIF affects arable lands use on irrigated fields. Since the constraints related to know-how requirements and majority of crops on fields inhibit change in arable land use, in this run, increased costs due to increased pesticide application just slightly alters the land use in the base run. In Figure

8.10, it is observed that, while COIF is decreased, CESIF (all in hectares) is increased because of the cost advantage.

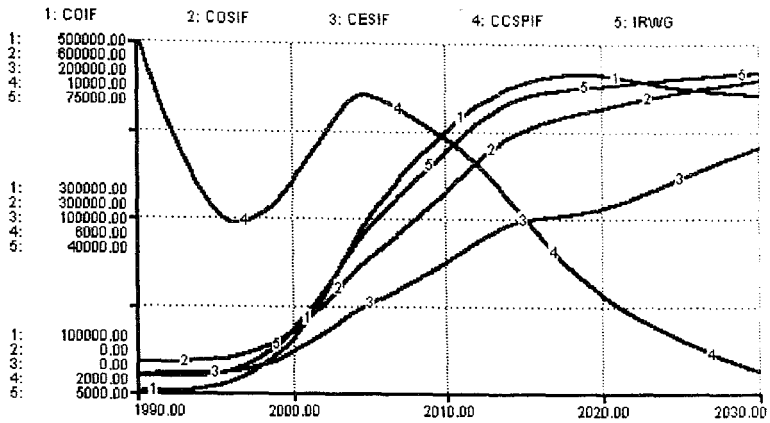


Figure 8.10. Arable land use on irrigated lands in "high pest resistance building" scenario.

Increased costs also affect the trade-off between crop production and animal husbandry. As crop production becomes less profitable, farmers tend to switch to livestock production on their farmlands (Figure 8.11). But, the relative increase in sheep on farm (sheep) does not alter sheep on rangelands; therefore, rangeland dynamics is not modified.

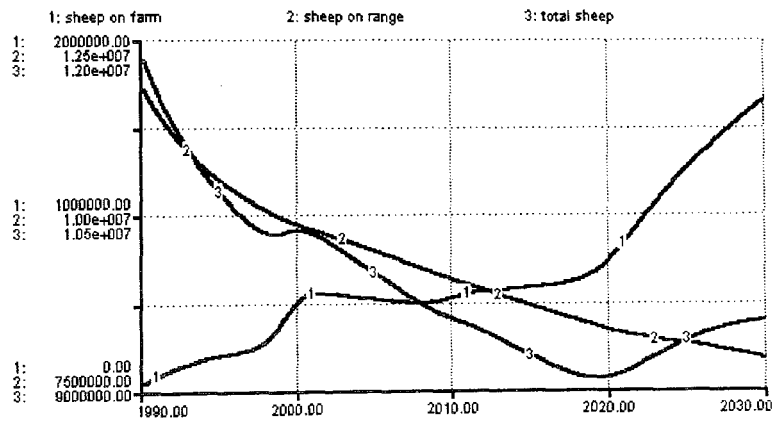


Figure 8.11. Livestock in "high pest resistance building" scenario.

VIII.1.2.2. Low Pest Resistance Building

In this section, a second analysis is performed by decreased pest resistance building. This scenario implies better pest management strategy; such that, chemicals introduced to the market do not so much stimulate pest resistance building and their field

applications are successfully monitored. In this scenario, pesticide consumption rates are considerably altered and average pesticide consumption on GAP irrigated lands is diminished (Figure 8.12.). When we consider for example, pesticide consumption rate for COIF, it is observed that the behavior of this variable is also modified, such that, its peak is delayed. This is because, decreased pest resistance building allows increased average farm residence times without any significant effect on pesticide application rates (kg/ha/year), but this time, farm residence times increase more, where at a different time point, pesticide consumption rates increase and alter land flows. In a way, this scenario delays extensive increase in pesticide consumption but still, a better management strategy based on crop rotation system is required.

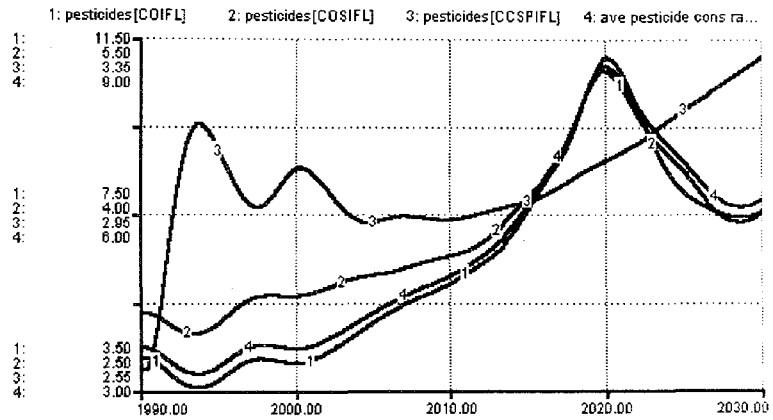


Figure 8.12. Average pesticide consumption rates in "low pest resistance building" scenario.

Corresponding land use on irrigated lands (allin hectares) is presented in Figure 8.13. In this run, COIF is increased significantly.

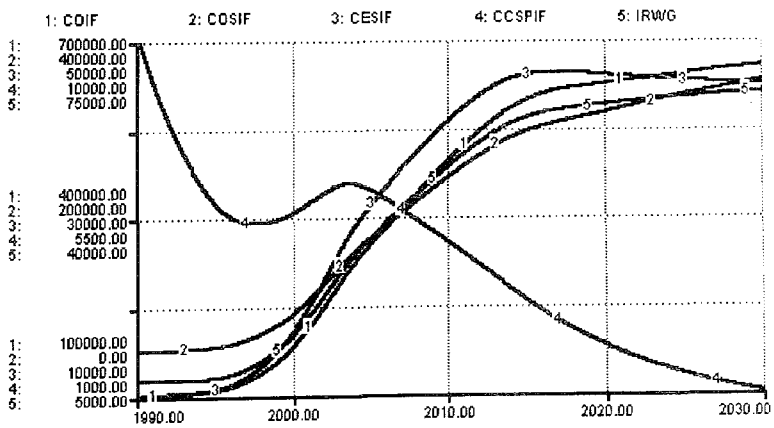


Figure 8.13. Arable land use on irrigated lands in "low pest resistance building" scenario.

VIII.1.2.3. Mild Fertilizer Response to Decreasing Yields

In this section, system performance with respect to changing fertilizer application rates is analyzed. This scenario implies changing farmer's response to compensate decreasing yields due to soil erosion and salinization. In the first run, "mild fertilizer response" scenario is performed. According to this scenario, fertilizer application rates with respect to diminishing yields are decreased. The behavior for fertilizer application rates and average leaching nitrogen is illustrated in Figure 8.14.

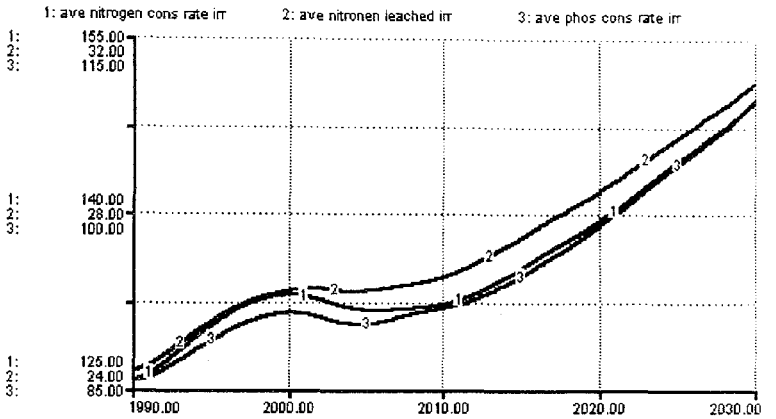


Figure 8.14. Fertilizer application and nitrogen leaching in "mild fertilizer response" scenario.

It is observed that, in this scenario, supply and yield for all agricultural commodities are decreased considerably and profitability of individual farm systems have dropped. But, since yields of all the commodities, therefore profitability of all farm systems are decreased, land use is not affected in this run. Total supply and yield for agricultural products are illustrated in Figure 8.15 .

An other modification in system behavior in "mild fertilizer response scenario" is related to animal husbandry (Figure 8.16.). As profitability of crop production is decreased with decreasing yields, farmers tend to increase their sheep on farmlands but again, this does not alter sheep on rangelands and therefore, rangeland dynamics is not modified.

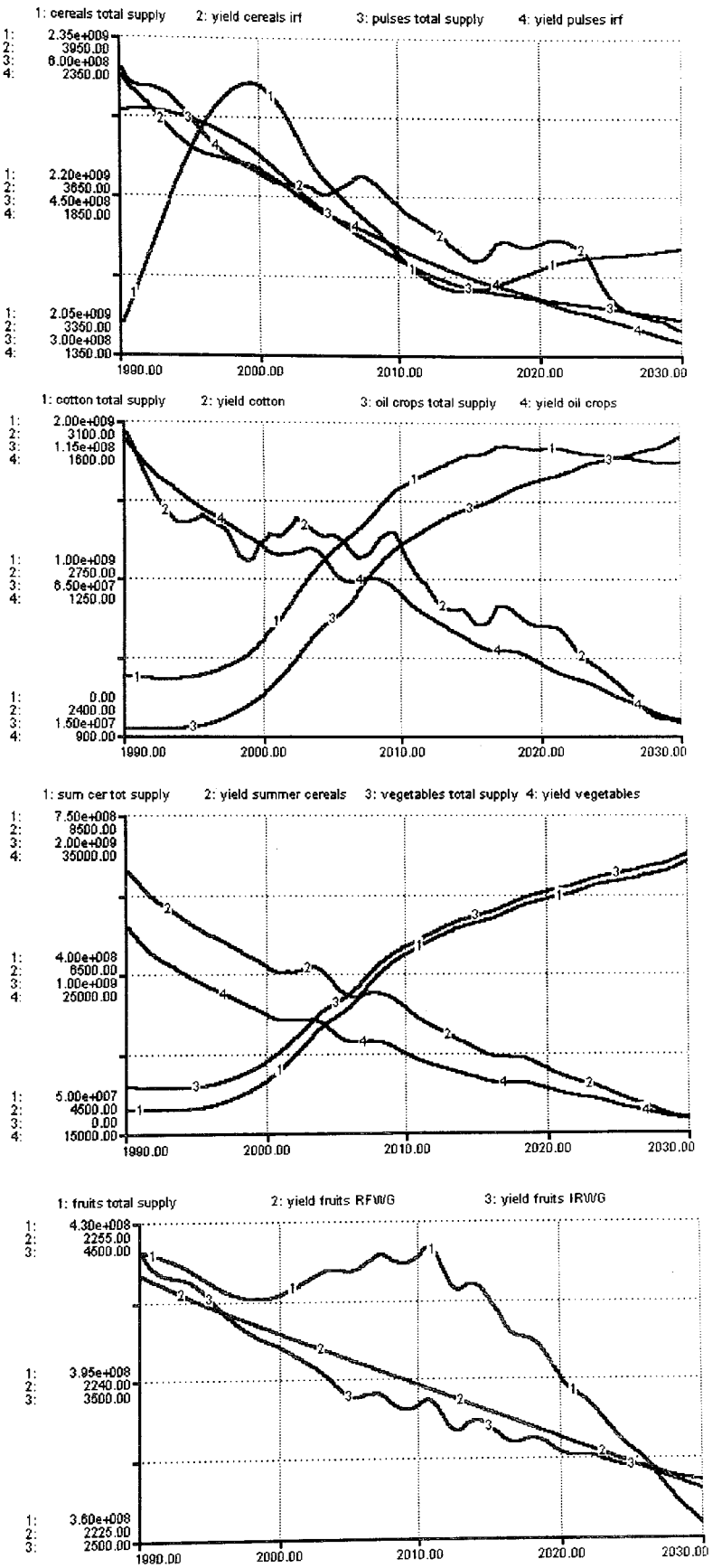


Figure 8.15. Agricultural supply and yield in "mild fertilizer response" scenario.

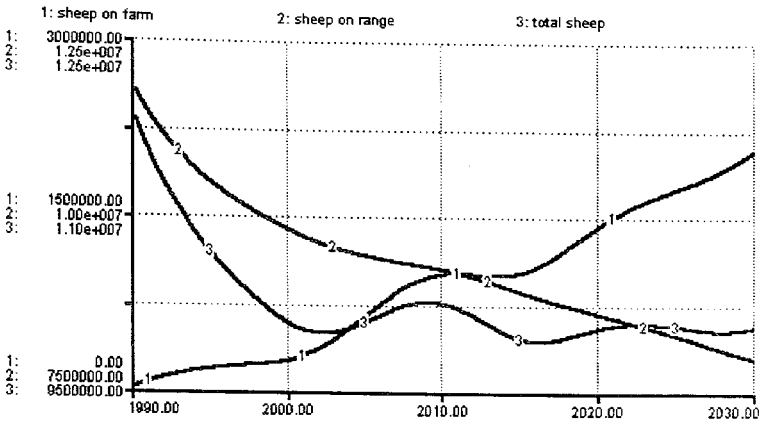


Figure 8.16. Sheep on farmlands and rangelands in "mild fertilizer response" scenario.

In this section, also, "strong fertilizer response" scenario is applied. But, no considerable change is observed in fertilizer application rates and yields since in the reference run, fertilizer response to decreasing yields is strong enough to more or less compensate yield losses due to erosion but not for salinization.

VIII.1.3. Scenario Analysis Related to Urbanization

In this section, model sensitivity to decreased urban land priority and increased urban initiation rates are analyzed. First scenario is "low urban land priority" which implies high land costs and strong agricultural land protection.

VIII.1.3.1. Low Urban Land Priority

In this run, it is observed that urban development is considerably inhibited (Figure 8.17.). In Figure 8.18., modified scale in urban job availability (unitless) and corresponding change in population parameters are illustrated. According to "low urban land priority scenario", since number of urban jobs are decreased, attractiveness of urban GAP and urban population is decreased, rural population is very mildly increased and finally, total population is decreased and emigration rate is increased, though they follow the same dynamic pattern with the base run.

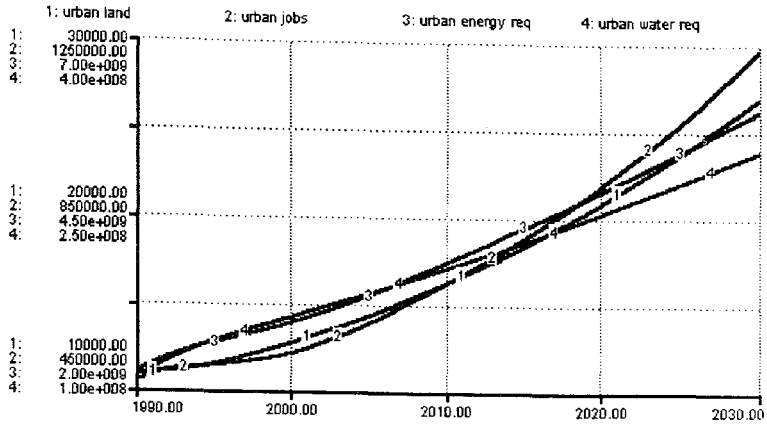


Figure 8.17. Urban growth in "low urban land priority" scenario.

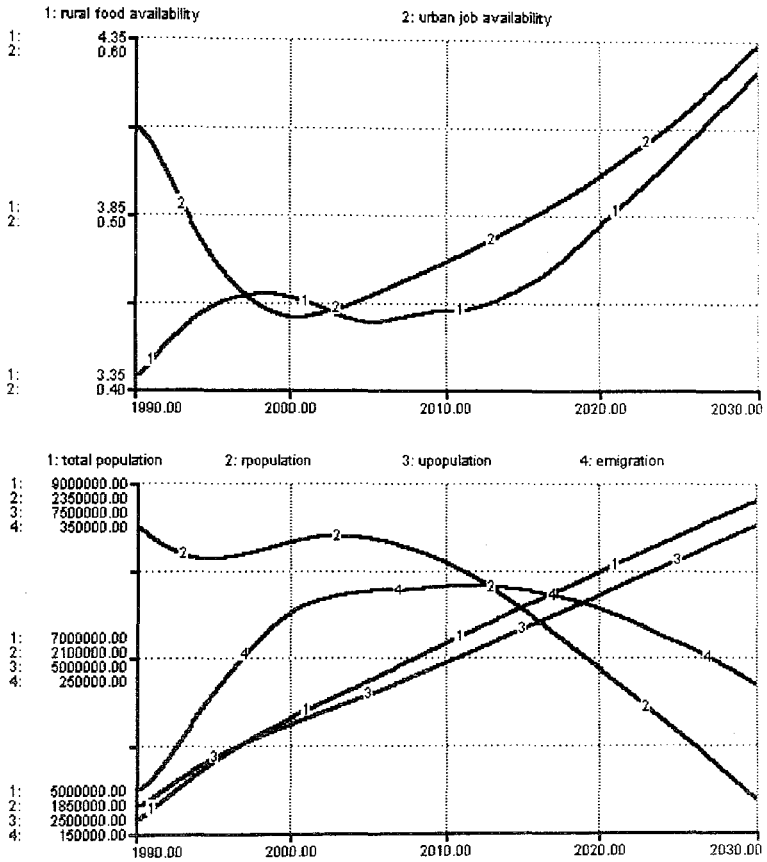


Figure 8.18. Food and job availability and population and emigration in "low urban land priority" scenario.

VIII.1.3.2. High Industry Initiation after Year 2000

Second scenario analysis in this section is "high industry initiation after year 2000" which implies enhanced capital availability, enhanced credits, low taxes and

changing attitude in enterprizing etc. According to this scenario, normal industry initiation rates are gradually doubled between years 2000 and 2010. System behavior in this run shows that, increasing industry initiation rates alone has a very mild increase in parameters representing urban growth, such as urban jobs, energy and water requirement and negligible effect on population parameters such as food and job availabilities and emigration rate. The stability of the system is mainly because of the rawmaterial and product availability constraint represented by negative feedback loops 3 and 4 in Figure 5.30. Since agricultural development can not respond to high urban development by increased agricultural production because of irrigation water scarcity, these negative feedback loops are not relaxed and a higher development rate is not achieved. Also, in this run, the negligible increase in urban demand for agricultural products results in relatively higher second cropping percentages which in turn slightly decreases irrigation water availability and alters irrigation development in hectares and increases fertilizer application rates per hectare.

VIII.1.4. Scenario Analysis Related to Population

In this section, model sensitivity to changing net birth rates and changing migration is analyzed.

VIII.1.4.1 Net Birth Rates Will Not Decrease

The first scenario analyzed in this section is "net birth rate will not decrease". The behavior for population variables under this scenario is presented in Figure 8.19. Though rural population (capita) keeps decreasing because of high emigration rate, rural and total populations are increased with respect to the base run. The relative increase in rural population creates pressure on rangelands and forests conversion to arable lands and slightly alters the scale in land use variables. Rural food availability and urban job availability are also illustrated in Figure 8.19. Both of these variables exhibit poor performance when compared with the reference run.

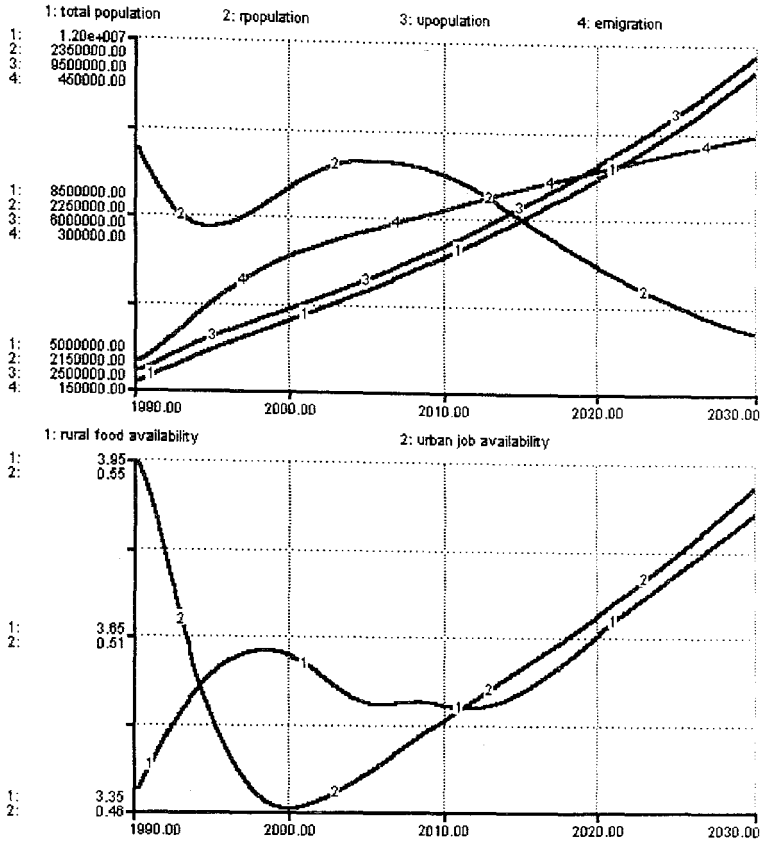


Figure 8.19. Population, emigration, food and job availability in "net birth rates will not decrease" scenario.

VIII.1.4.2. Net Birth Rates Will Significantly Decrease

Second scenario analyses the situation if net birth rate is decreased more than it is assumed in the base run. This scenario is called "net birth rate will significantly decrease". The results concerning population variables are presented in Figure 8.20. Rural population decreases significantly, total and urban populations begin to reach their asymptotes at about 7 at 8 millions respectively. After year 2005, emigration rate follows a sharp decrease. Improved behavior for rural food and urban job availability variables are also illustrated in Figure 8.20.

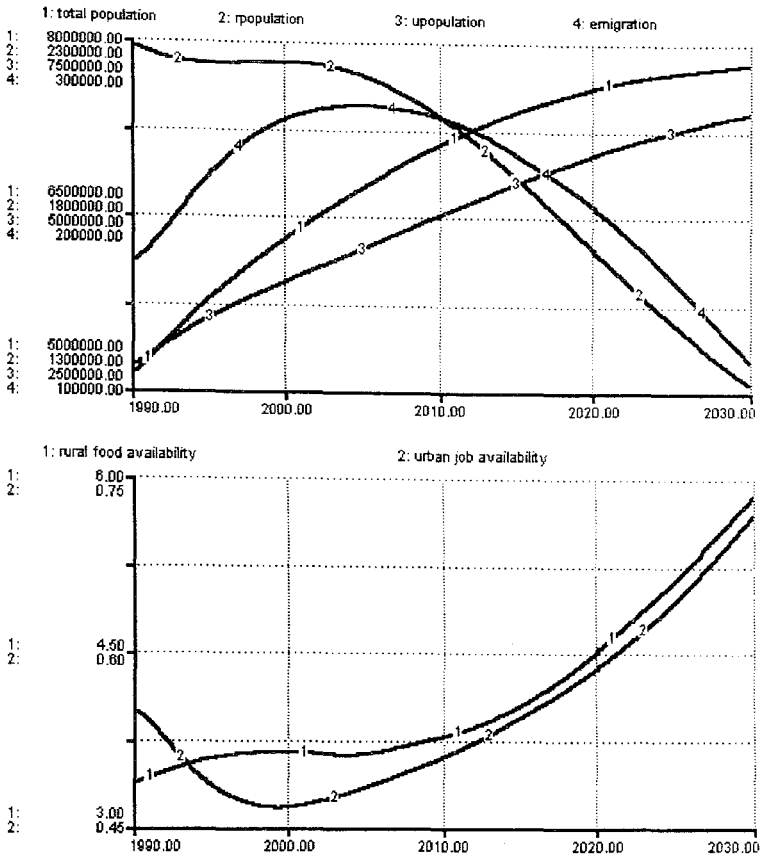


Figure 8.20. Population, emigration, food and job availabilities in "net birth rates will significantly decrease" scenario.

According to this scenario, behavior of the parameters representing urbanization are also modified. Though number of urban jobs do not significantly decrease, urban job, water and land requirements decrease by decreasing urban population and urban housings (Figure 8.21).

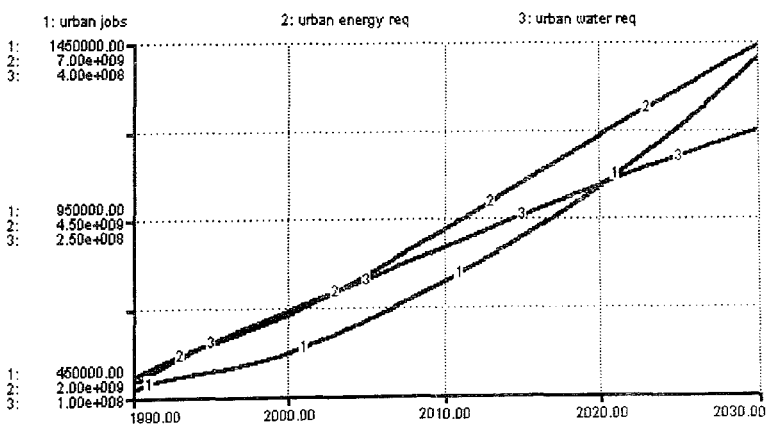


Figure 8.21. Urbanization in "net birth rates will significantly decrease" scenario.

The implications of this scenario on land use, decreased pressure on rangelands and forests conversion to arable lands is demonstrated on Figure 8.22.

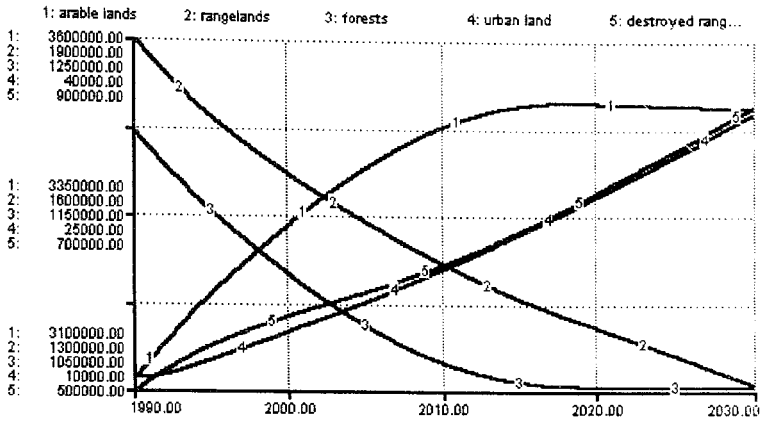


Figure 8.22. Land use in "net birth rate will significantly decrease" scenario.

Also, modified urban growth under both scenarios, "net birth rates will not decrease" and "net birth rates will significantly decrease" have effects on irrigation development rates and second cropping percentages through changing urban demand for agricultural products. These alterations effect irrigation water availability on individual farmlands and therefore yields. But, since the scale of change in urbanization and therefore, on urban demand for agricultural products are low, these modifications are not so much significant.

VIII.1.4.3. Emigration Rates will Decrease after Year 2000

Third scenario related to population assumes decreasing rural and urban emigration rates in GAP region after year 2000. This scenario implies that high emigration rates between the years 1990 – 1997 will gradually decrease between the years 2000 and 2010. According to this run, the behavior of population parameters are illustrated in Figure 8.23. Both total and urban population values increase with respect to the base run but, rural population follows an S-shaped growth after year 2000, where the growth is stopped at 2.6 million capita after year 2020 because of poor rural food availability. Also, total regional emigration is controlled just for a short period of time, up to year 2010, but it does not significantly decrease because of worsening rural food and urban job availability

parameters. In this run, scale of the parameters representing urban growth do not change (see Figure 8.24).

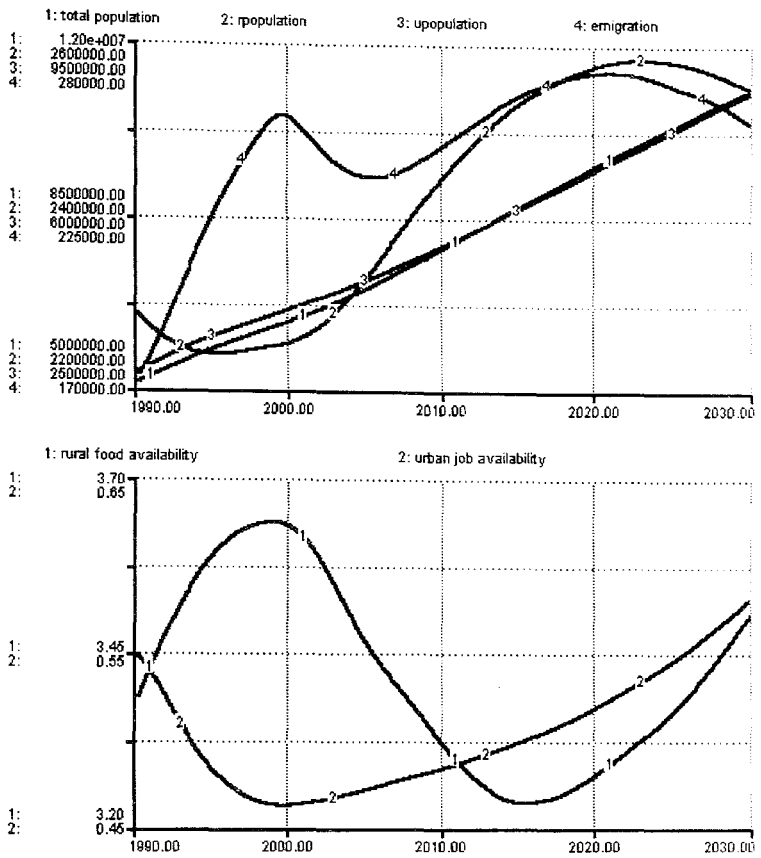


Figure 8.23. Population, emigration, food and job availabilities in "emigration rates will decrease after year 2000" scenario.

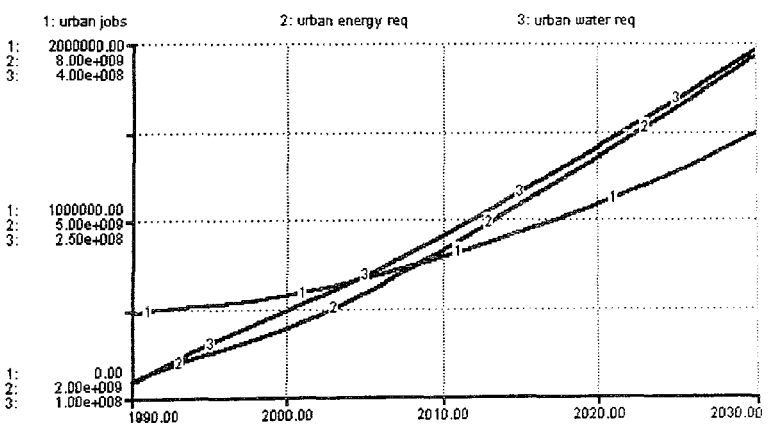


Figure 8.24. Urban growth in "emigration rates will decrease after year 2000" scenario.

Increased rural population alters the scale in land use dynamics as pressure for rangelands and forests conversion to arable lands (all in hectares) is increased. Modified behavior for land use is demonstrated in Figure 8.25. Arable lands are significantly increased and rangelands, forests and destroyed rangelands are decreased according to this scenario.

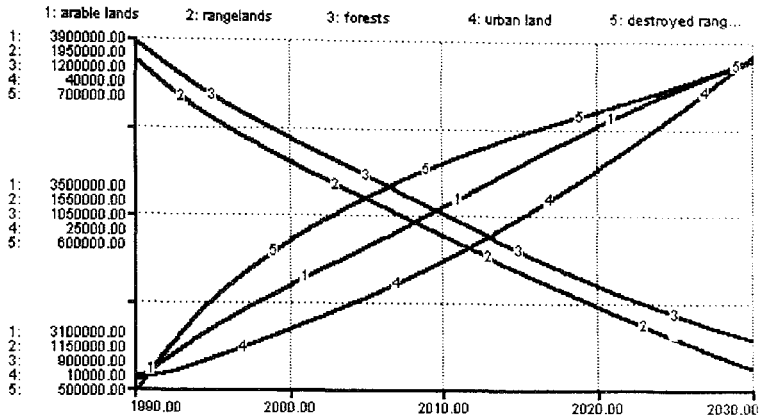


Figure 8.25. Land use in "emigration rates will decrease after year 2000" scenario.

In this scenario, an other change is observed for cereal and pulses supply (kg/year) and yields (kg/ha/year). Since, rangelands and forests are converted to rainfed lands, land for cereals and pulses production has increased and therefore, total supply for these commodities are increased. But, as increased rural population and increased rural population intensity implies violation of fallow practices, average safe yield for these products are decreased (Figure 8.26.).

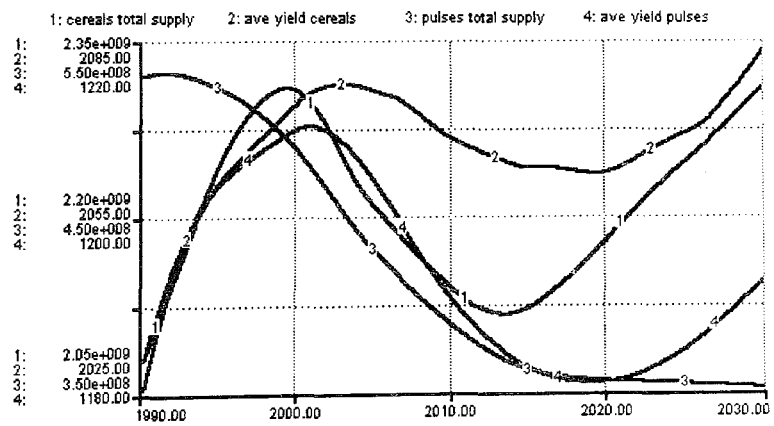


Figure 8.26. Cereals and pulses supply and yield in "emigration rates will decrease after year 2000" scenario.

VIII.2. Policy Analysis

In this section, several policy analyses related to GAP water resources, salinization control, rangeland improvement, urban employment policy and market interventions for certain commodities are performed. In the first section, analysis related to water resources are demonstrated.

VIII.2.1. Policy Analysis Related to Water Resources

This set of policy analysis includes tests related to GAP construction rate and tests related to the trade off between hydropower production and irrigation release in regional scale.

VIII.2.1.1. Constructions Stop After Year 2000

The behavior of the variables related to water resources development according to this policy are illustrated in Figure 8.27. Irrigated lands stagnate at 300000 ha by year 2005, and maximum firm hydropower production reaches 17 billion kwh/year where actual firm energy production drops to 14 billion kwh/year as irrigation release increase by 4.5 million m^3/year till year 2005.

According to this policy, alteration of land regimes in rural GAP, therefore rural food availability and modification of urbanization, therefore job availability in urban GAP affect actually not the behavioral characteristics but the scale in population dynamics. Relevant variables are illustrated in Figure 8.28. In GAPSIM, as agricultural production and demand for agricultural production factors support urban growth, in this run, urbanization rate slows down with decreased agricultural development and therefore, urban job availability is not improved as it is in the reference run. Since population absorption capacity of urban GAP has diminished, the overall affect in population parameters is

higher rural population and lower urban and total population. Though it follows similar dynamics with the base run, emigration rate is considerably higher.

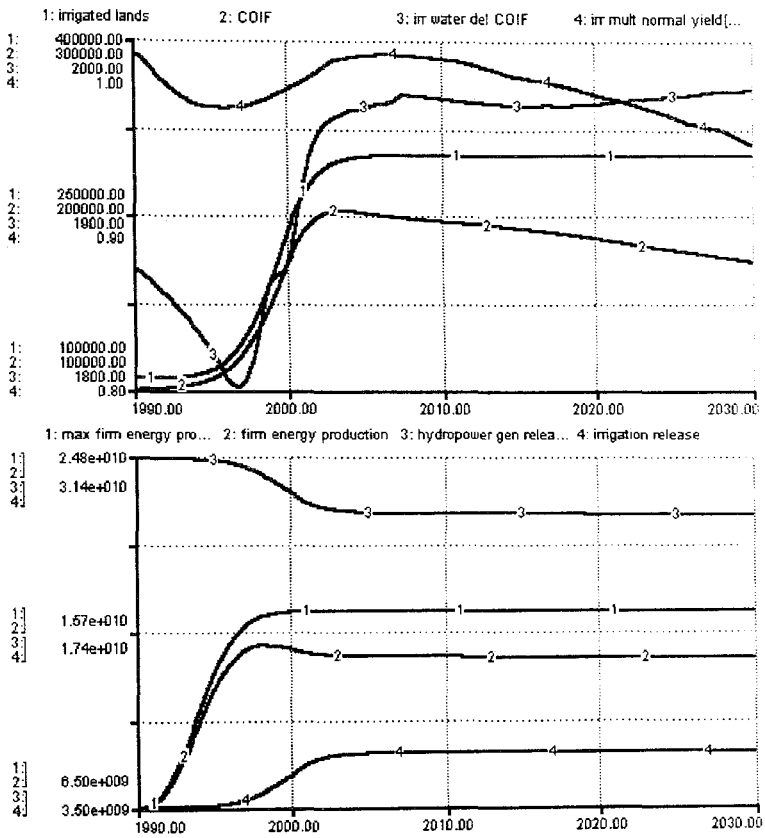


Figure 8.27. Water resources development under "constructions stop after year 2000" policy.

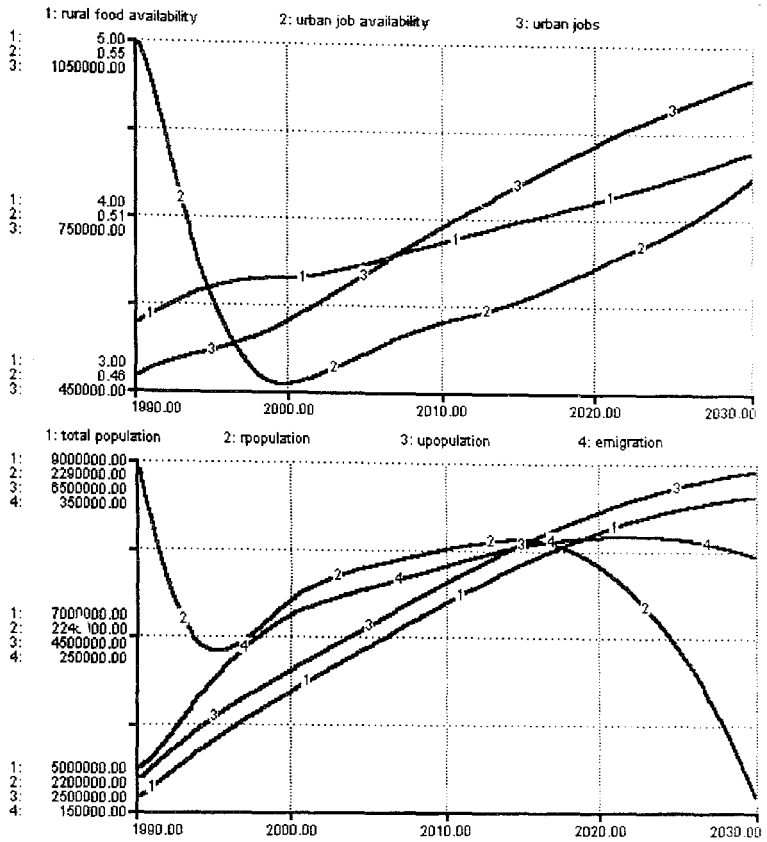


Figure 8.28. Population dynamics under "constructions stop after year 2000" policy.

With respect to this scenario, as rural population is increased, pressure on rangelands and forests conversion to arable lands increase and rate of increase in urban land diminish. Here again, the dynamic behavior of variables representing aggregated land groups do not change but scales are altered, such that, the ultimate value for arable lands increase but for rangelands, forests and urban land decrease (see Figure 8.29).

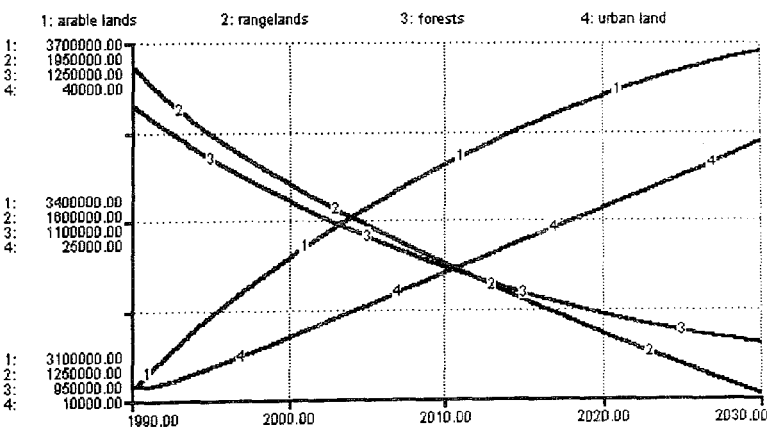


Figure 8.29. Land use under "constructions stop after year 2000" policy.

Up to here, though some alterations are observed for the illustrated variables related to urbanization, population and land use, the scale of modifications are rather moderate. GAP does not promise a significant stimulation in urbanization and population absorption capacities of the cities in this time horizon unless factors other than agricultural raw material supply and agricultural input demand are concerned. In both cases, strong urban immigration arouses similar characteristics in urbanization. In fact, the stability of the urban system was illustrated by the negative feedback mechanisms in the causal loop diagram in Figure 5.30.

In this scenario, of course, land flows within arable lands are altered significantly since land transformation from rainfed to irrigated fields is not realized. Regional supply of the products cotton, oil crops, summer cereals, vegetables and fruits are notably decreased in this run. Total supply for cereals increase and for pulses decrease though the average yield for these crops on GAP fields do not change significantly, when compared with the base run. The supply and average yield for these crops are illustrated in Figure 8.30.

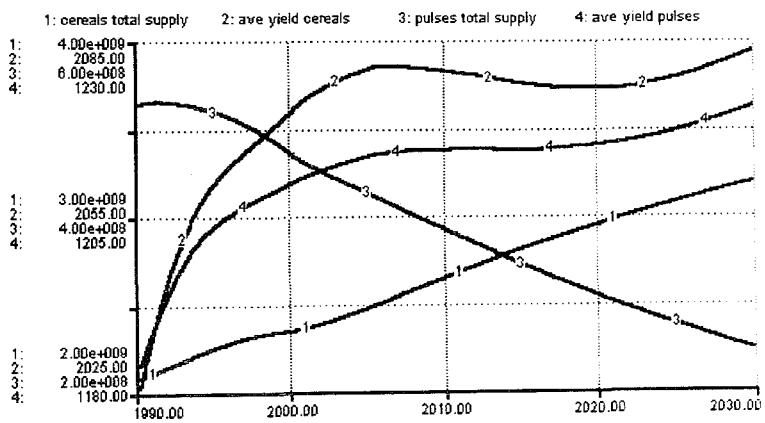


Figure 8.30. Cereals and pulses supply and yield under "constructions stop after year 2000" policy.

Also, livestock quantity fed on farmlands diminish but this difference does not have a significant effect on total livestock population since rangeland dynamics is not significantly altered (see Figure 8.31.).

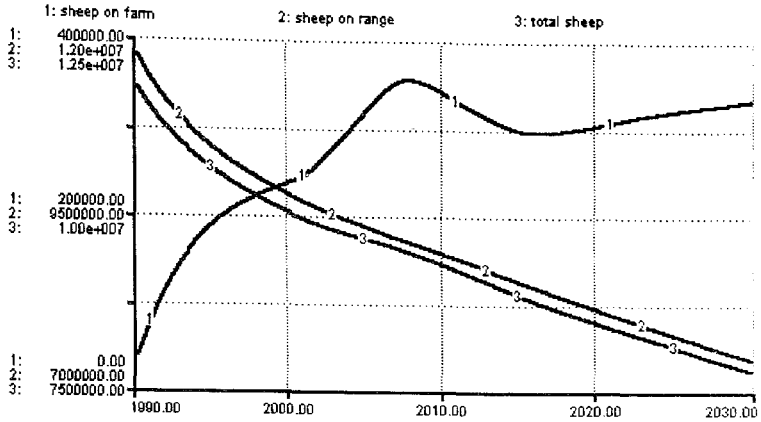


Figure 8.31. Livestock under "constructions stop after year 2000" policy.

When we come to the variables concerned with land degradation and pollution (see Figure 8.32.), average salinization profile (mg/l) for the irrigated fields decreases significantly as first and second feedback loops in Figure 5.5., which reinforce increase in salt concentration of irrigation through drainage and subsurface discharge processes weaken as regional quantity of drainage and subsurface discharge into freshwater supplies diminish with diminished irrigation in hectares. Average mineral nitrogen leached from irrigated fields (kg/ha/year) decreased since yield-inhibiting affect of salinization diminished and increase in fertilizer consumption rate has declined. Also, in this run average pesticide consumption rate stagnates at a higher value than it is in the base run. This modified behavior is related to changing average residence times of certain farm practices.

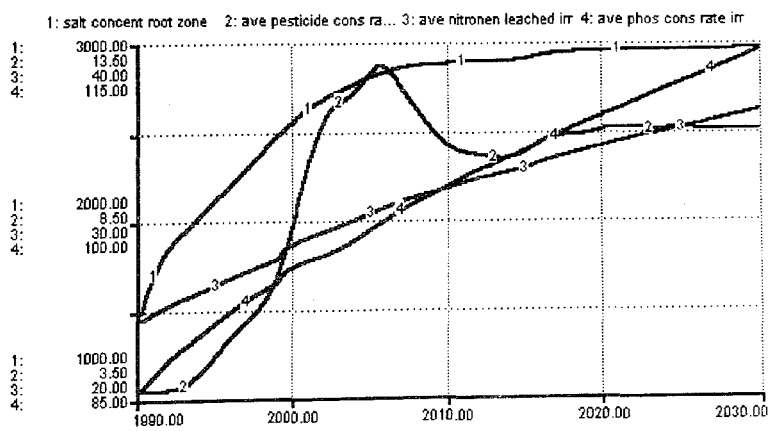


Figure 8.32. Land degradation and pollution under "constructions stop after year 2000" policy.

VIII.2.1.2. Constructions Slow Down after Year 2000

According to this scenario, rate of GAP constructions begin to slow down after year 2000 and by year 2015, hydropower production and irrigation release capacities do not reach their targeted values. In this run, irrigated lands reach over 600 thousand hectares and firm energy production stagnate at about 16 billion kWh/year where irrigation release reaches about 11 million m^3/year (see Figure 8.33.).

Effect of this scenario on land use, land degradation, pollution, agricultural production and population are very similar to "constructions stop after year 2000" scenario where the same modifications on the base run occur but scale differ. The modified behavior is illustrated in Figures 8.34. through 8.38. In this run, again, there is considerable decrease in cotton, oil crops, summer cereals, vegetables and fruits production but the behavior of these variables are not presented.

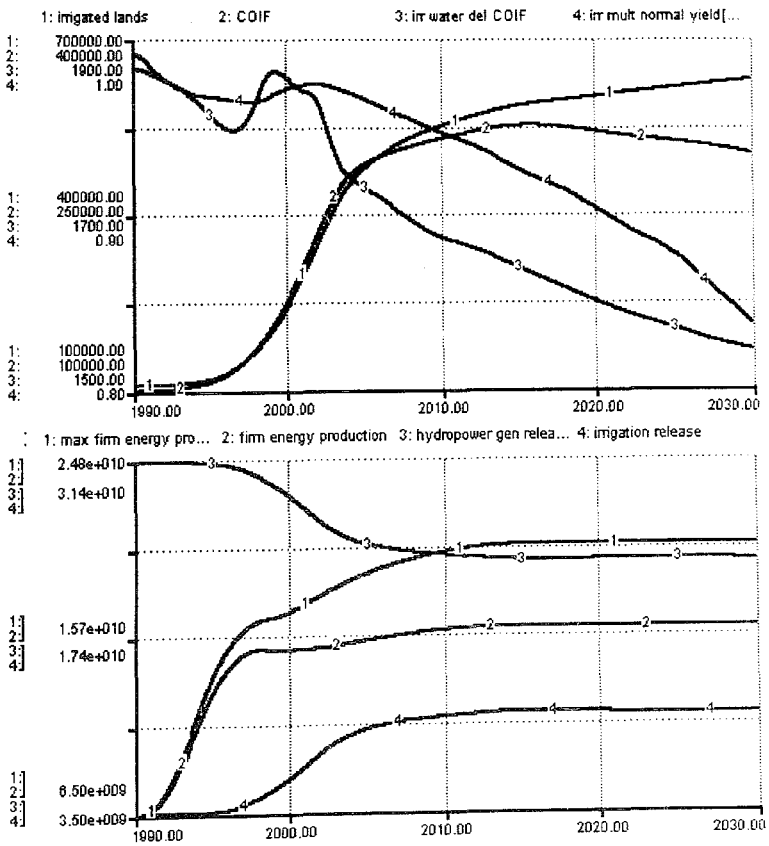


Figure 8.33. Water resources development under "constructions slow down after year 2000" policy.

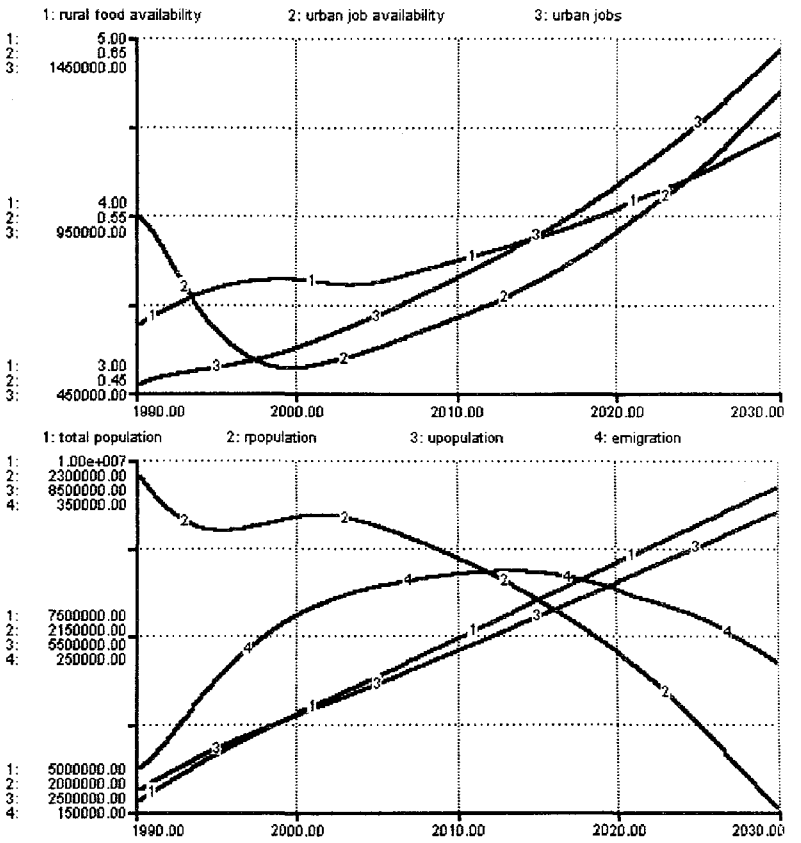


Figure 8.34. Population dynamics under "constructions slow down after year 2000" policy.

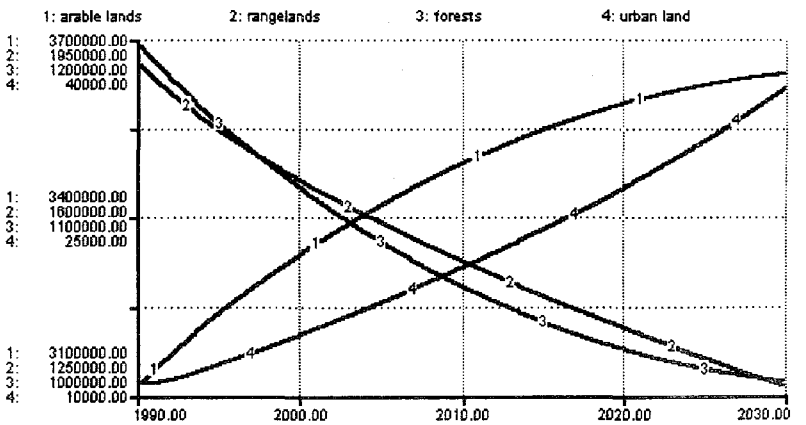


Figure 8.35. Land use under "constructions slow down after year 2000" policy.

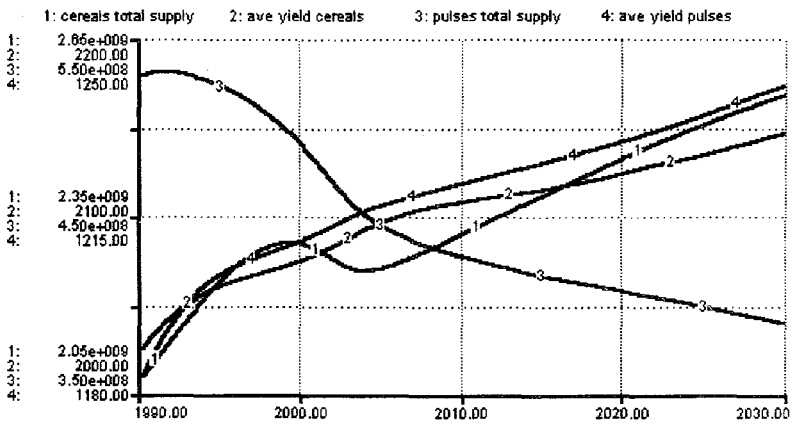


Figure 8.36. Cereals and pulses supply and yield under "constructions slow down after year 2000" policy.

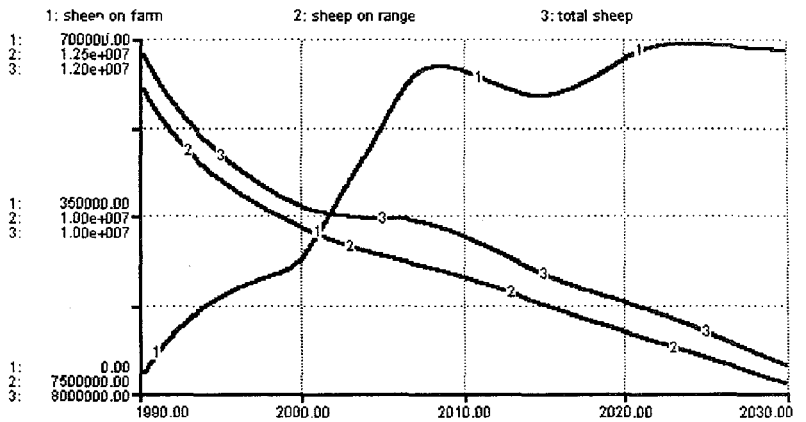


Figure 8.37. Livestock under "constructions slow down after year 2000" policy.

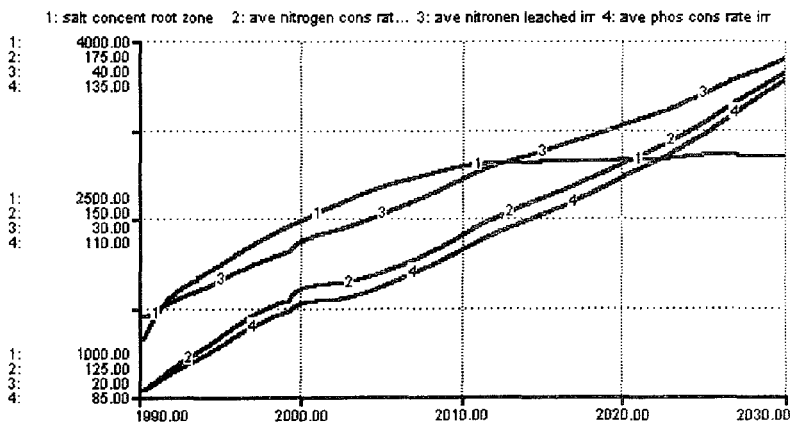


Figure 8.38. Land degradation and pollution under "constructions slow down after year 2000" policy.

VIII.2.1.3. Low irrigation Priority after Year 2000

In the reference run, irrigation priority was gradually dropped from 1 to 1.5 between the years 2000 and 2020 so that irrigation release was stopped at 18 billion m^3/year, which makes about half of firm basin yield, and the ultimate value for firm energy production was 17.5 billion kWh/year. In this run, irrigation priority is gradually much more lowered between the years 2000 and 2020 and a higher hydropower production is achieved. The behavior of parameters related to water resources development are illustrated in Figure 8.39. According to this policy, irrigated lands reach 700 thousand hectares by year 2030 and especially after year 2020, irrigation water availability per hectare, for example for COIF suddenly decreases. This results in a considerable decrease in yields of high consumptive crops since up to that time, their land occupation has increased significantly. Firm energy production is increased and reached an ultimate value of 21 billion kWh/year and irrigation release is stagnated at about 9 billion m^3/year.

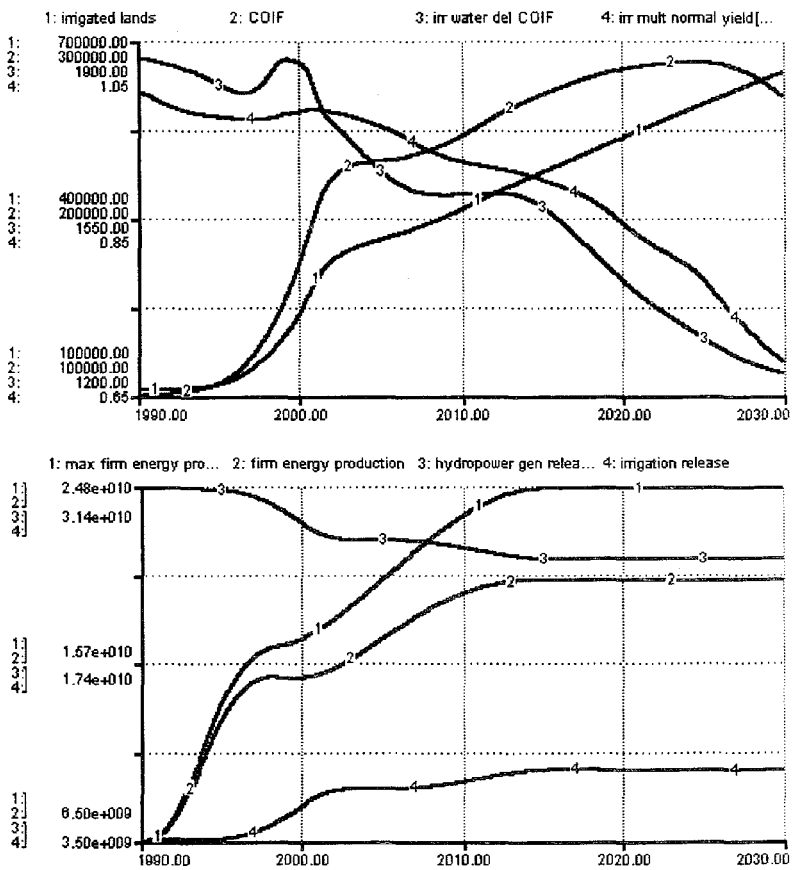


Figure 8.39. Water resources development under "low irrigation priority after year 2000" policy.

This policy has considerable effects on arable land use, reminding the importance of water allocation among hydropower production and irrigation. The modified behavior for arable lands are illustrated in Figure 8.40. Since rate of transformation from rainfed farming to irrigated farming is inhibited by this policy, all rainfed fields and rainfed wine garden increase when compared with their reference behavior. More important is the modification in behavior of irrigated lands. By this policy, as constraint on irrigation releases are gradually increased after year 2000, lands allocated for high consumptive-use crops, especially for cotton, increase without any perception of future scarcity and when this situation begins to inhibit plant growth significantly, after year 2020, production of less consumptive-use crops such as cereals become more advantageous and CESIF makes a sharp take-off.

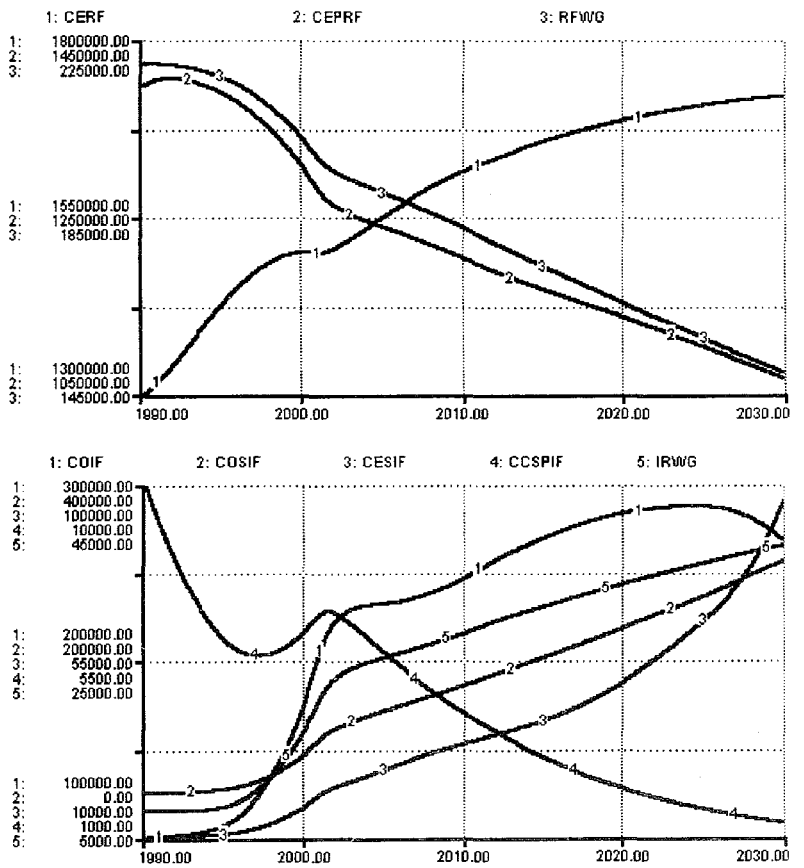


Figure 8.40. Arable land use under "low irrigation priority after year 2000" policy.

The altered behavior in arable land use has implications on variables representing land degradation and pollution (see Figure 8.41.). Average salinization profile decreases

because of the reasons stated in section VIII.2.1.1. As yield inhibition by salinization is decreased, rate of increase in fertilizer application and leaching nitrogen slows down. Also, changing arable land use and decreasing cotton monoculture especially after year 2010 significantly alters the average pesticide consumption rate. Average pesticide consumption rate declines by declining cotton monoculture lands.

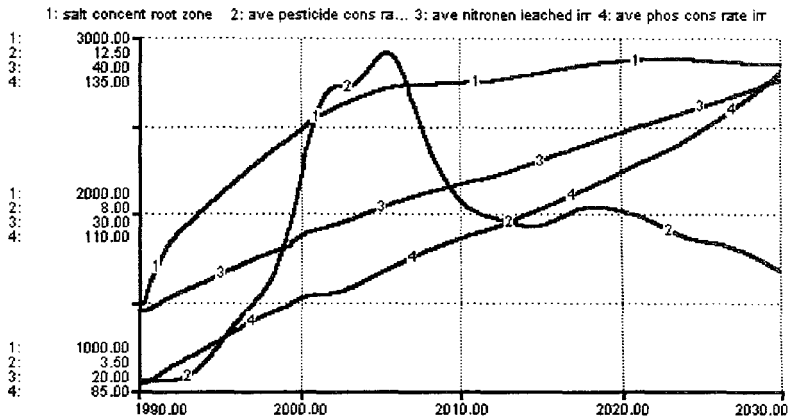


Figure 8.41. Land degradation and pollution under "low irrigation priority after year 2000" policy.

In this run, since irrigated lands were decreased, total supply for the agricultural products cereals and pulses increased and total supply of cotton, oil crops, summer cereals and vegetables have decreased. No significant change is observed in average yield of these products.

When we come to the variables representing urbanization and population dynamics, here again, the behavioral characteristics do not change but scales alter as it has occurred in "constructions slow down after year 2000" scenario. Therefore, decreased agricultural production inhibits urban growth. Behavior of relevant variables are demonstrated in Figures 8.42. and 8.43.

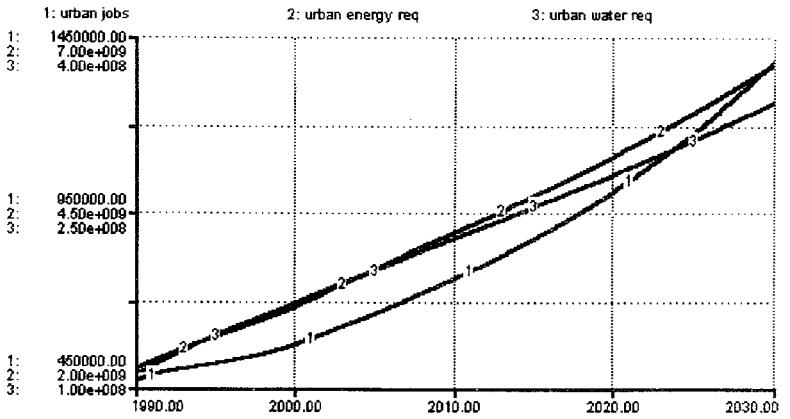


Figure 8.42. Urban growth under "low irrigation priority after year 2000" policy.

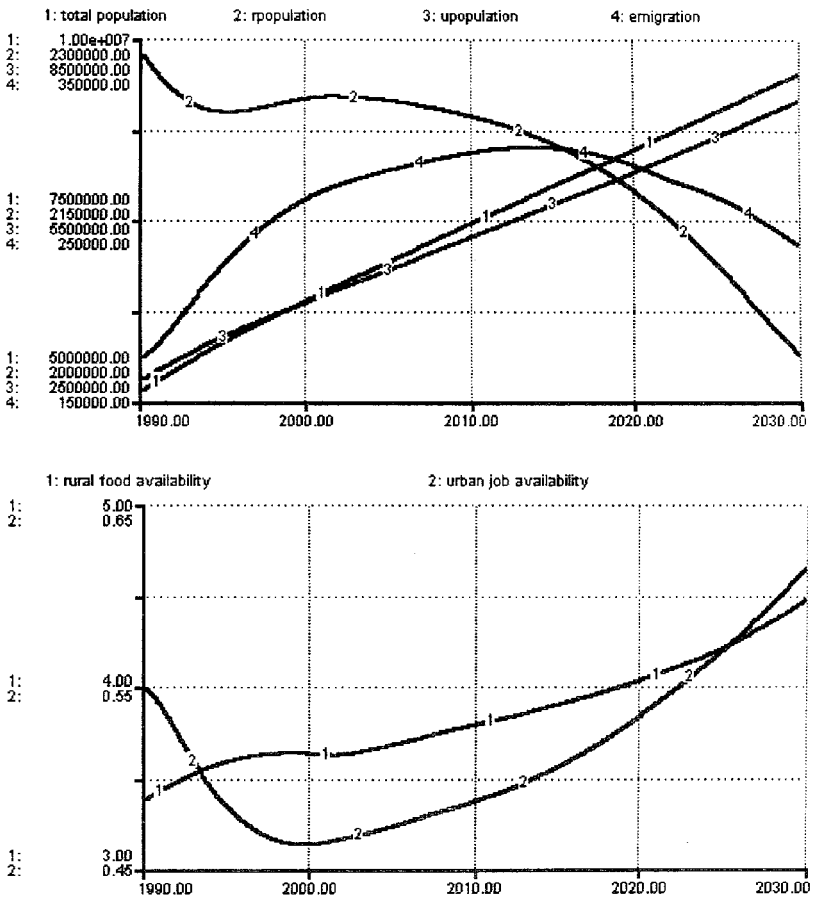


Figure 8.43. Population, food and job availability under "low irrigation priority after year 2000" policy.

The relative effect of changing rural population and urban growth on land use is illustrated in Figure 8.44, where an increase in arable lands and decrease in rangelands, forests and urban lands is observed.

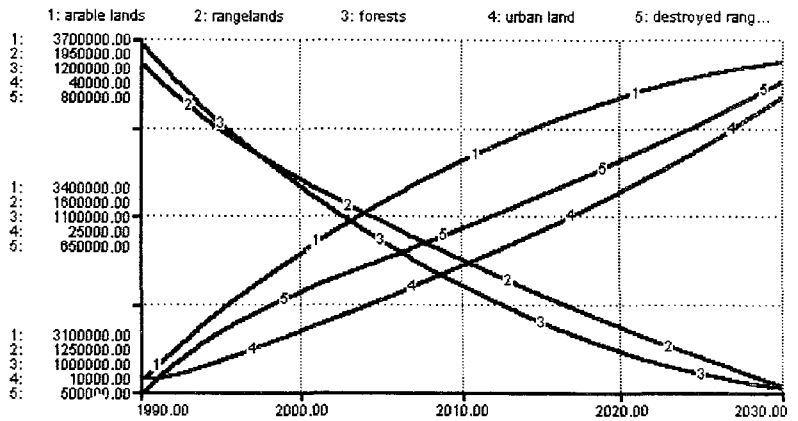


Figure 8.44. Land use under "low irrigation priority after year 2000" policy.

VIII.2.2. Salinization Control

In this section, model behavior under efficient salinization control policy is tested. Drainage efficiency in irrigation and salinization sector is set to 0.8, so that greater portion of infiltration is drained out and percolation is avoided. This policy corresponds to weakening the second and third positive feedback loops in Figure 5.5. The average salinization profile calculated in this run is presented in Figure 8.45. Note that, salt accumulation is still in process as drainage water is given to the freshwater supplies, therefore first positive feedback loop in Figure 5.5. is still active.

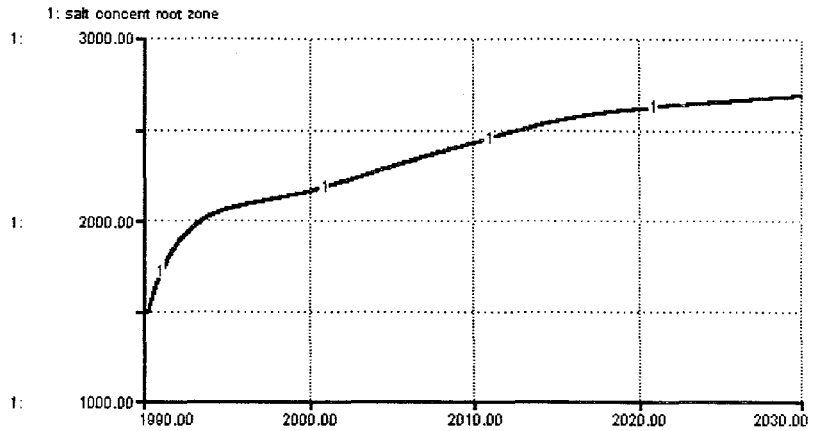


Figure 8.45. Salt concentration at soil root zone under "salinization control" policy.

Salinization control strategy has significant effect on arable land use on irrigated lands. In the long term, high salt concentration at soil root zone may stimulate production of salt resistant crops as yields; therefore profitability of vulnerable crops will decrease. Hence in GAPSIM, under salinization control, lands attributed to cotton monoculture – COIF decrease in favor of CESIF because, the most salt resistant crop cotton looses its advantage relative to other summer crops such as oil crops, summer cereals and vegetables. The modified behavior for arable land use on irrigated lands is illustrated in Figure 8.46. If non-economical constraints determining crop preference were abandoned as in section VIII.1.1.1, much more considerable alterations would be observed.

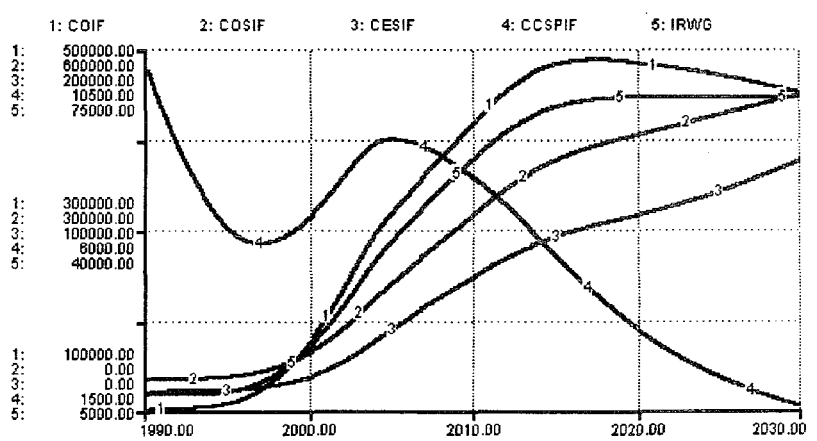


Figure 8.46. Arable land use on irrigated lands under "salinization control" policy.

Decreased salinization and modified arable land use have important effects on variables representing agricultural pollution. As observed in Figure 8.47, average pesticide consumption rate is lowered and it begins to decline after year 2010. Also, as yield-inhibiting effect of salinization is decreased, increase in fertilizer consumption rates slow down and corresponding values for fertilizer application and leaching nitrogen decrease.

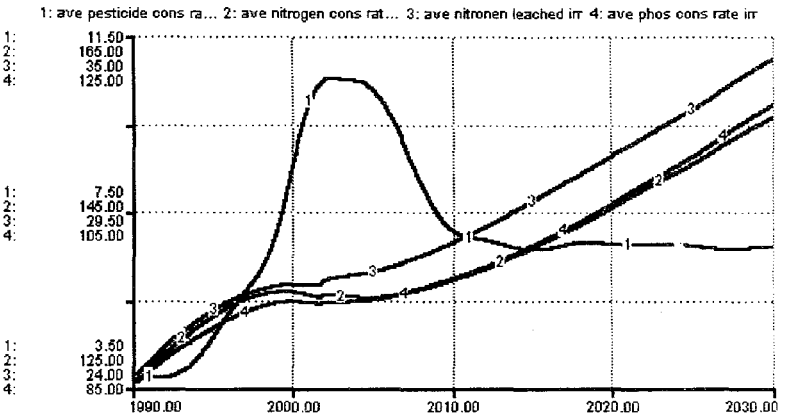


Figure 8.47. Agricultural pollution under "salinization control" scenario.

Sailinization control has considerable effect on yields whose implications on land use are already demonstrated. Modified yields under "salinization control" are illustrated in Figure 8.44. Though there is not a significant change in cereals yield, cereals total supply increase by increased CESIF. Pulses yield and supply increase slightly. Cotton supply decrease and cotton yield is not significantly effected by this policy. Both supply and yield quantities for oil crops, summer cereals, vegetables and fruits increase in this run.

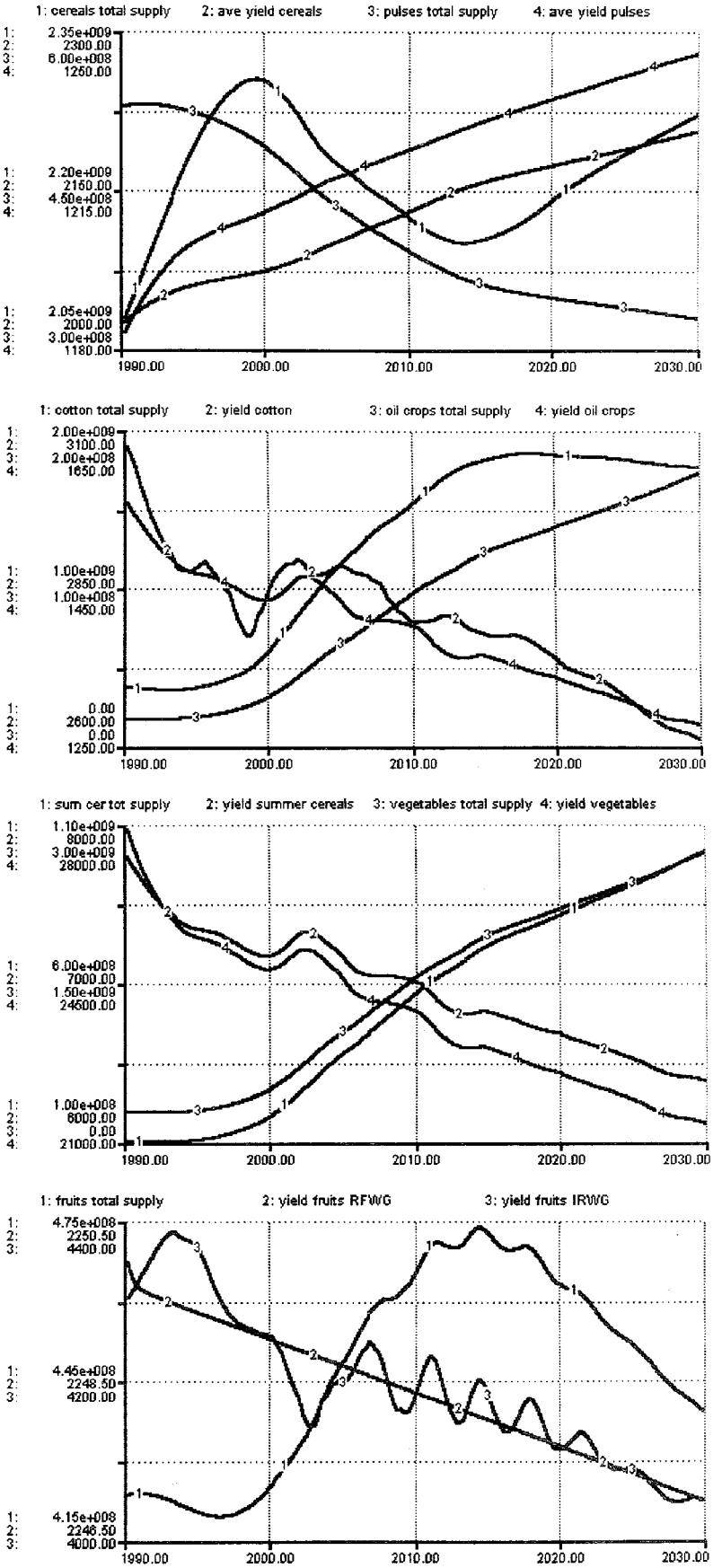


Figure 8.48. Agricultural production and yields under "salinization control" policy.

Also, increased yields, therefore increased profitability of farms modify the trade-off between crop production and animal husbandry in favor of crop production. But, sheep on rangelands is not significantly affected by this change on sheep on farmlands. New behavior for sheep on farmlands and rangelands is illustrated in Figure 8.49.

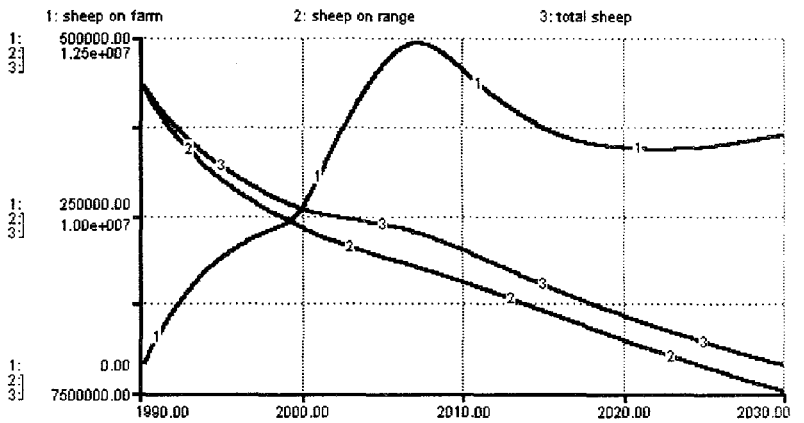


Figure 8.49. Livestock under "salinization control" policy.

"Salinization control" scenario does not have any significant effect on parameters related to urbanization and population dynamics.

VIII.2.3. Policy Analysis Related to Rangelands

In this section, effects of rangelands and forests improvement policies on system behavior are demonstrated.

VIII.2.3.1. Rangelands Improvement

In this section, a governmental policy based on rangelands improvement is simulated. According to this policy, improvement of destroyed and poor rangelands begin in year 2000 and the improvement fraction gradually reach 5% of the destroyed lands per year by year 2010. The modified behavior in land use is illustrated in Figure 8.50. According to this run, significant amount of destroyed rangelands are converted to rich and poor rangelands after year 2000.

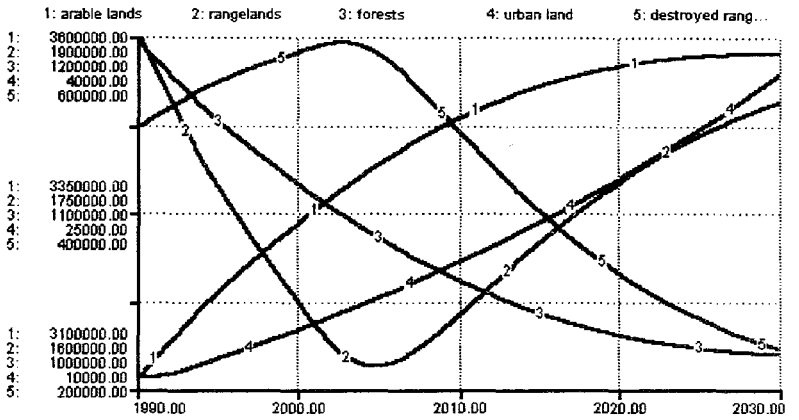


Figure 8.50. Land use under "rangelands improvement" policy.

The modified behaviors of individual rangeland groups are illustrated in Figure 8.51. After year 2000, rich rangelands increase and poor and destroyed rangelands decrease.

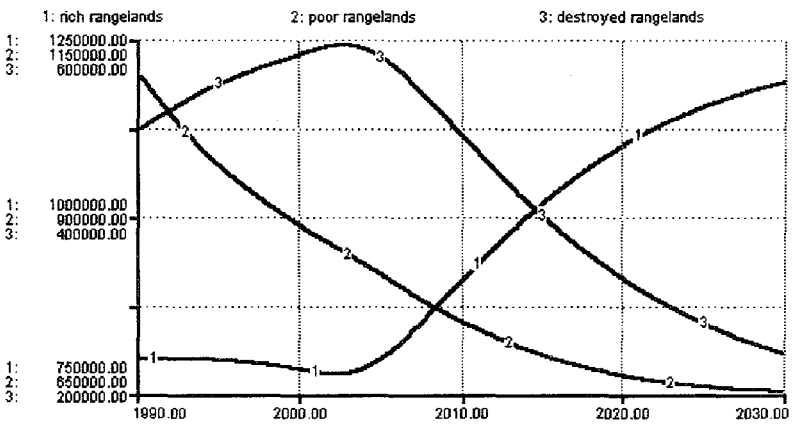


Figure 8.51. Rangelands under "rangelands improvement" scenario.

Rangelands improvement has positive effect on sheep on rangelands as increased rangeland grass and decreased rangeland crowding supports animal husbandry on rangelands. But rangelands improvement alone, can not stimulate a sharp increase in animal husbandry. Resulting behavior for livestock quantities are demonstrated in Figure 8.52, and it is observed that, by year 2030, total sheep can just recover its initial value through an increase beginning after year 2000.

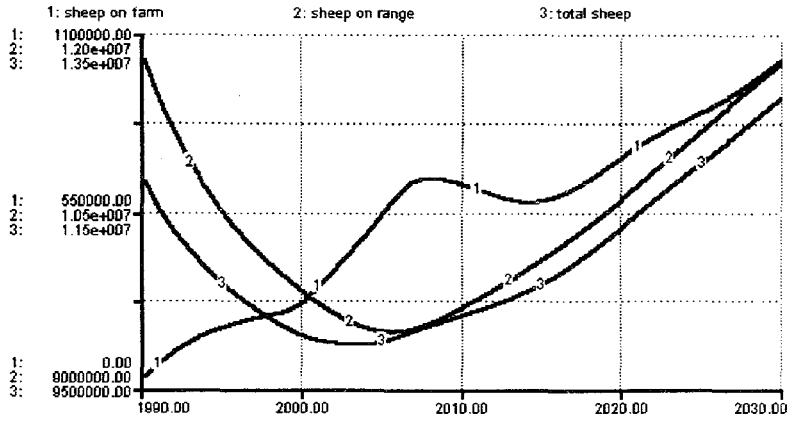


Figure 8.52. Livestock under "rangelands improvement" scenario.

VIII.2.3.2. High Rangeland Cost After Year 2000

According to "high rangeland cost after year 2000" policy, rangeland costs are gradually increased by a factor of three between years 2000 and 2010. The effect of this policy on livestock is illustrated in Figure 8.53. By increasing the rangeland costs, people tend to shift their sheep from rangelands to farmlands and also people tend to quit ranging. This results in a decrease in sheep on rangelands and an increase in sheep on farmlands. But total sheep is considerably decreased.

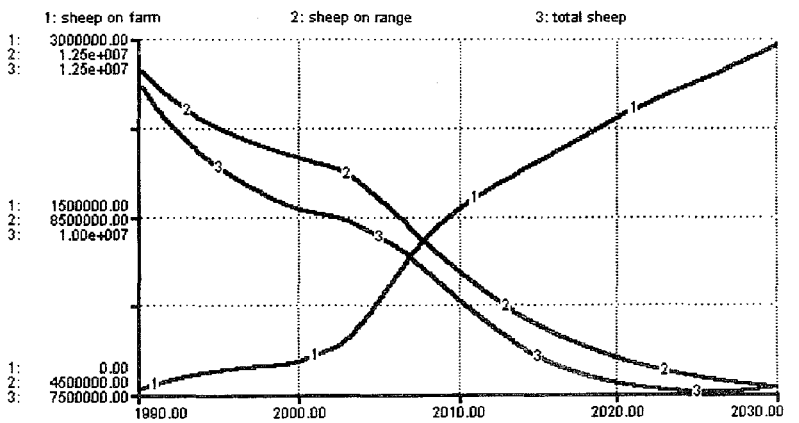


Figure 8.53. Livestock under "high rangeland cost after year 2000" policy.

The effect of this policy on land use and rangelands is illustrated in Figure 8.54. Rangelands destruction stops by year 2010 and rangelands begin to increase slowly after this year.

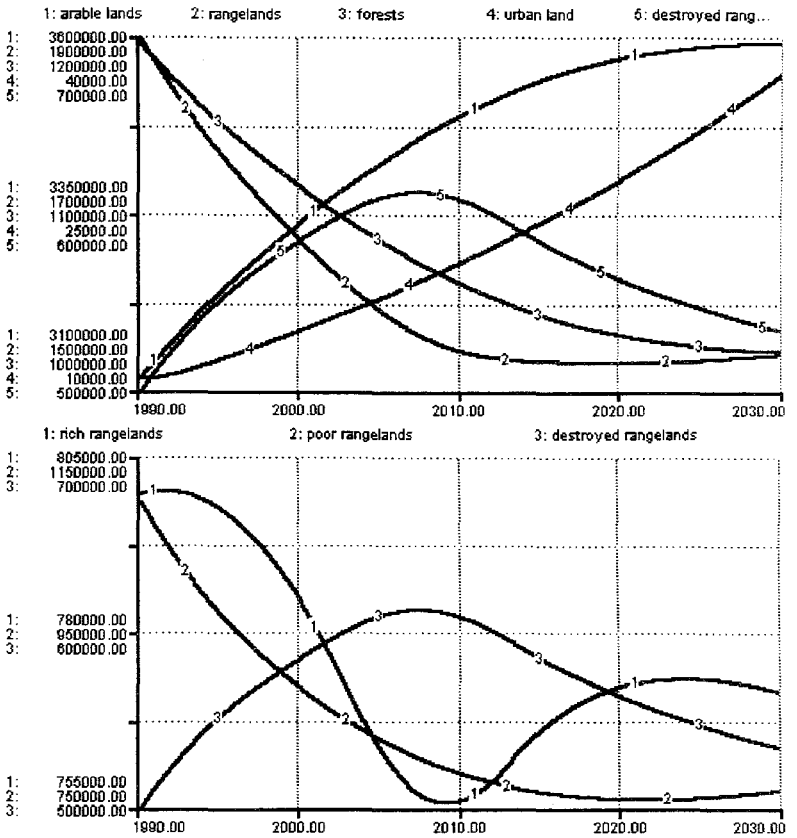


Figure 8.54. Land use and rangelands under "high rangeland cost after year 2000" policy.

VIII.2.4. High Public Employment

In this section, effect of increased public employment policy on model behavior is investigated. For this purpose, desired urban employment rate is increased, in order to create more public jobs and to increase overall urban job availability. According to this policy, urban growth rate is increased (see Figure 8.55). But, this does not imply a serious improvement in urban job availability as high employment opportunity increases the attractiveness of urban GAP and stimulates urban immigration. Variables representing rural population are not modified in this run. Job and food availabilities and corresponding population behavior are illustrated in Figure 8.56.

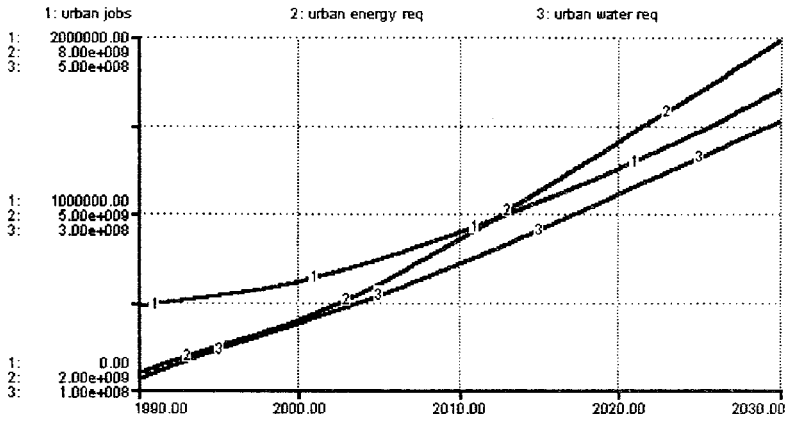


Figure 8.55. Urban growth under "high public employment" policy.

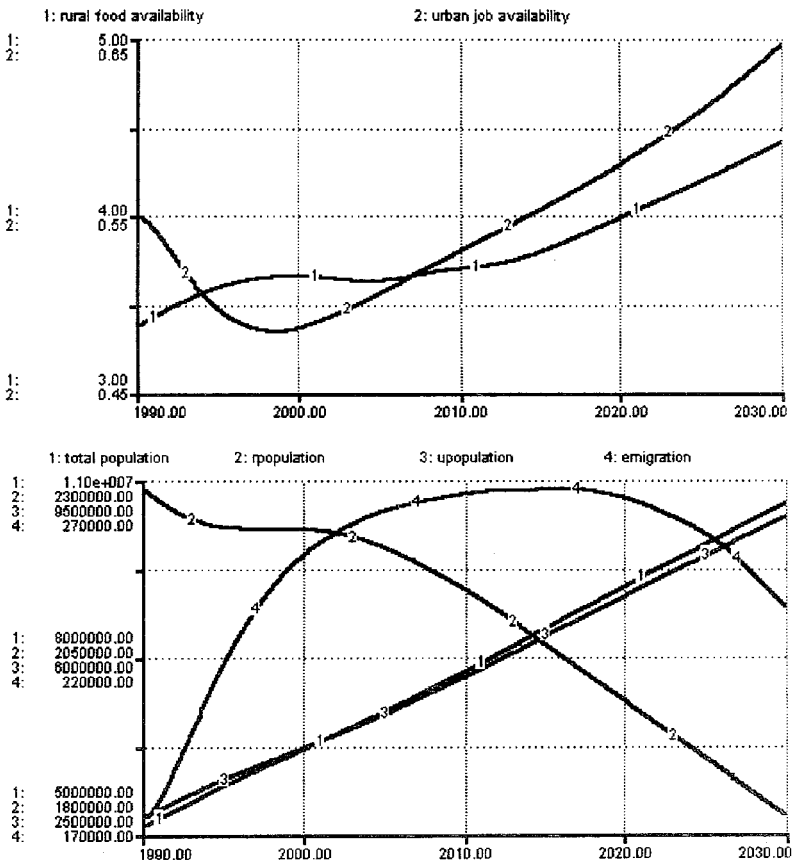


Figure 8.56. Food and job availabilities and population under "high public employment" policy.

VIII.2.5. Policy Analysis Related to Market Interventions

At the beginning of this section, a scenario analysis is performed. According to this scenario, increasing portion of pulses, vegetables, fruits and livestock production are allocated for industrial production in urban GAP between the years 2000 and 2020. Generated model behavior shows that, increasing raw material for agro-industries mildly stimulate development of this industry group but this does not create a significant overall effect neither on agricultural production nor on urban growth and population dynamics.

In the following sections, long term effects of several government intervention policies on agricultural production, land degradation, pollution and other relevant model behavior are demonstrated. These policies are based on governmental purchases, which intend to fix higher prices for certain commodities.

VIII.2.5.1. Government Promotes Summer Crops

According to this policy, governmental purchases for summer crops such as oil crops, summer cereals and vegetables are increased up to 30% of their respective regional supply by year 2000. This policy has considerable effects on arable land use. When compared with the base run, lands for cotton–summer crops rotation, COSIF, and lands for cereals-summer crops rotation, CESIF, increase and lands for cotton monoculture, COIF, decrease. Modified behavior is illustrated in Figure 8.57.

Changing land use on irrigated lands alters the behavior of some variables representing agricultural pollution. While, an improved behavior is achieved for average pesticides consumption rate because of relatively decreased COIF and decreased COIF residence time, increasing intensity of summer crops increase average fertilizer consumption rates and average leaching nitrogen in GAP irrigated fields. The behaviors of these variables are shown in Figure 8.58.

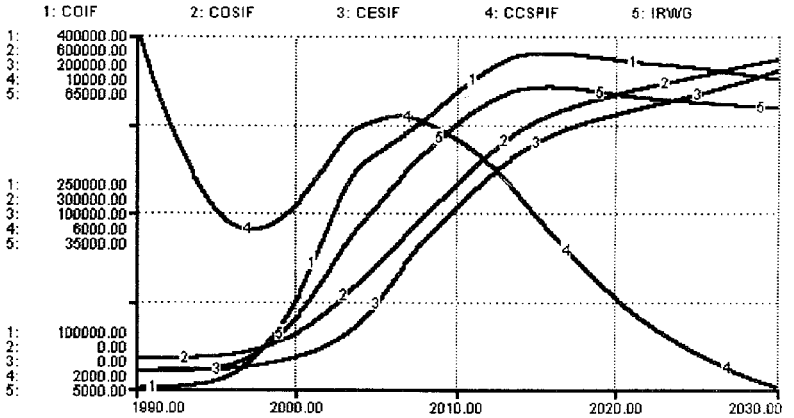


Figure 8.57. Arable land use under "government promotes summer crops" policy.

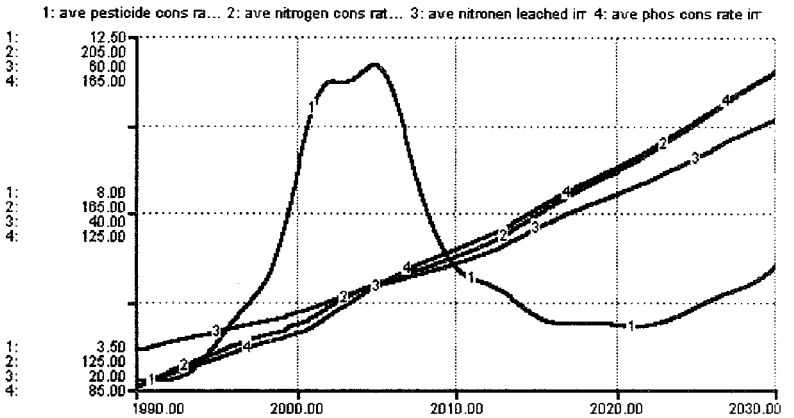


Figure 8.58. Agricultural pollution under "government promotes summer crops" policy.

This policy does not effect yields for agricultural products but changes the regional supply for these commodities. In this run, cereals, oil crops, summer cereals and vegetables supply are increased, cotton and fruit supply are decreased and pulses supply did not change (see Figure 8.59.). It is observed that, regional supply for governmentally supported commodities increase in the long term. If, constraints determined by traditional attitudes in crop preference were eliminated, these policies would be more effective.

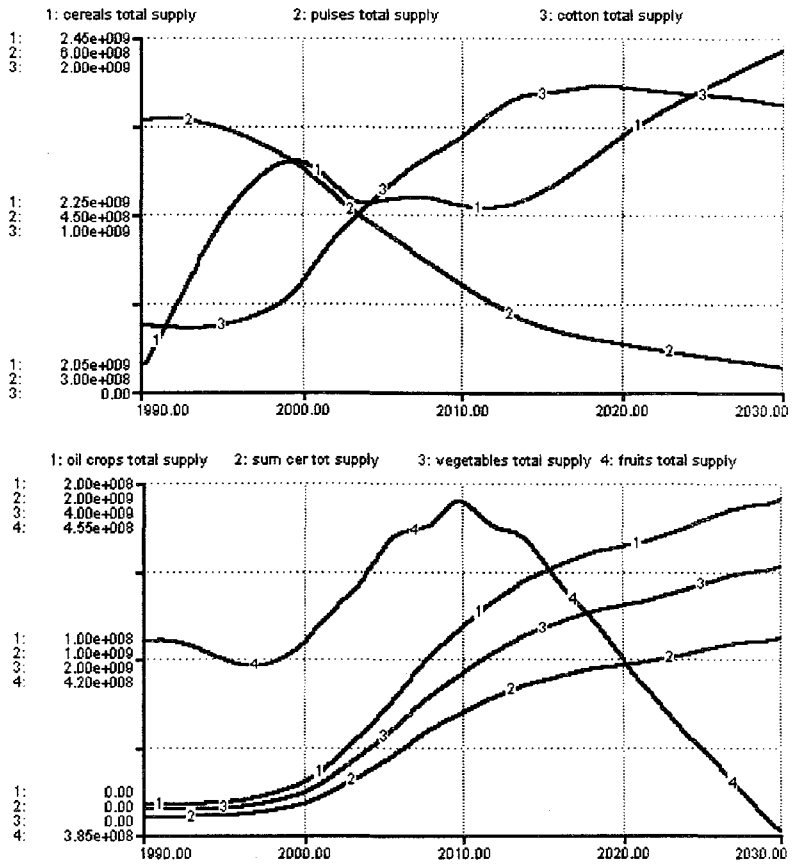


Figure 8.59. Agricultural production under "government supports summer crops" policy.

Also, increased agricultural profitability by increased governmental purchases effect livestock quantity. Farmers tend to switch from animal husbandry on rangelands to summer crops production and sheep on farmlands decrease (Figure 8.60). This modification does not effect sheep on rangelands and rangeland dynamics.

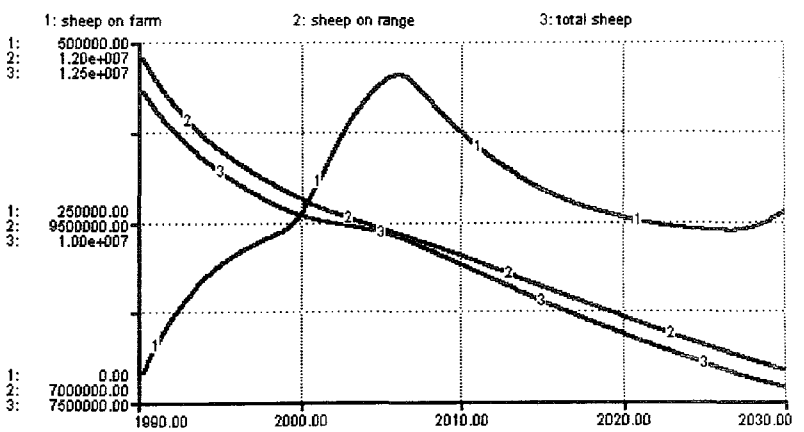


Figure 8.60. Livestock under "government promotes summer crops" policy.

VIII.2.5.2. Government Promotes Animal Husbandry

According to this policy, government purchases for livestock products are increased up to 30% of regional production by year 2000. The modified behavior for sheep is demonstrated in Figure 8.61. By this policy, sheep on rangelands are increased in the long term but this improvement can not recover initial total sheep as rangelands destruction is in process. Furthermore, as a portion of sheep on farmlands is shifted to rangelands, increased sheep on rangelands elevate rangeland destruction and in the long term prepare a sharp collapse in sheep on rangelands. If one carefully compares the behavior of sheep on range with that in the base run, it can be observed that, first, the rate of decrease slows down but by year 2010 it increases. The altered scales for rangelands are illustrated in Figure 8.62.

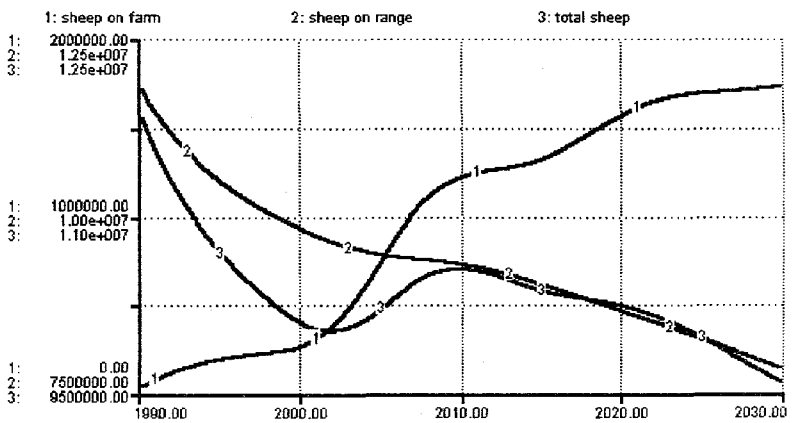


Figure 8.61. Livestock under "government promotes animal husbandry" policy.

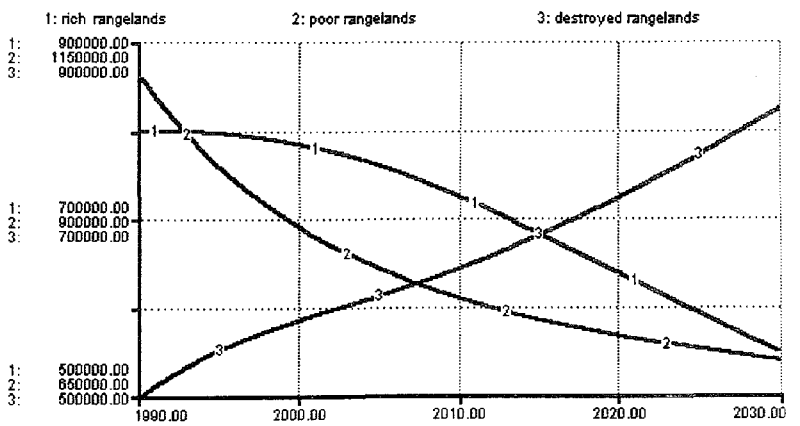


Figure 8.62. Rangelands under "government promotes animal husbandry" policy.

IX. SUMMARY OBSERVATIONS AND RESULTS

GAPSIM reference behavior points to many potential problems concerning water availability, land use, land degradation, agricultural pollution, agricultural production, urbanization and population in GAP. In this chapter, most significant problems suggested by the model base run are summarized and possible scenario and policy combinations yielding improved behavior patterns are discussed.

According to the base run, half of the firm basin yield of Euphrates and Tigris is utilized for irrigation purposes but, as there is a strong bias toward the highest consumptive-use crop cotton, GAP faces a significant irrigation water scarcity where total irrigated lands stagnate far below the targeted value and yield losses due to water deficit. Also, increasing cotton monoculture increase other environmental problems related to pesticide consumption rates, salinization and fertilizer application rates. Water scarcity, salinization and erosion processes result in decreasing yields where losses are tried to be compensated through increasing the fertilizer application.

Traditional attitudes in crop preference have important effect on crop selection together with economical factors. At this stage, it would be useful to identify two environmental factors affecting land allocation for crops on irrigated fields. Since pesticides are high-cost farm inputs, their varying application rates to sustain conventional yields under changing pest conditions have considerable effect on crop selection. Improved or poor pest management strategies would effect the intensity of certain crops on GAP agricultural system in the long term. A second factor is salinization process, which creates bias towards salt tolerant crops such as cotton and cereals. Hence, a successful salinization control policy on GAP irrigated lands would also effect crop selection in the long term. Therefore, creating initiative for an improved cropping pattern on GAP irrigated fields, avoiding water scarcity, intense pesticide application, high salt concentration and high fertilizer application would require integration of policies related to traditional attitudes, market and environment.

In the base run, though net regional birth rates were set as decreasing functions of time, urban growth can not provide satisfactory urban employment for the urban population within the simulation horizon. Raw material availability for the agro-industries, and agricultural demand for production factors from these industries act as insufficient stabilizing factors after year 2020. Rapid agricultural development yielding high input rates for agro-industries together with elevated industry initiation rates implying enhanced capital availability, subsidies etc., may create increased urbanization rates and improved urban employment rates. As improved urban employment implies high urban immigration rates and lower rural population, satisfactory urban employment rates would result in increased rural nutritional levels (food availability) and decreased pressure on rangelands and forests.

Model base run points significant problems related to rangelands and animal husbandry. As livestock asset of the region is tied to the rangelands, overgrazing and declining rangeland quality results in decaying livestock quantity. Increased livestock on farmlands is far below the traditional quantities supported by the rangelands of the region. Also, under the conditions where rangeland destruction is in process, stimulation of animal husbandry through economic initiatives creates a temporary improvement in livestock quantity but prepares a future collapse through increased rangeland destruction rates. Therefore, rangeland improvement is a must for satisfactory results in livestock management.

Scenario and policy analysis in sections VIII.1. and VIII.2. provide insights for designing improved system performance with respect to the variables concerning environmental factors such as land use, land degradation and agricultural pollution; economical factors such as agricultural production and urban job availability; and rural nutritional levels (rural food availability). But, non of these analyses is sufficient on its own to create satisfactory behavior. Therefore, in this chapter, some scenario and policies are combined to demonstrate efficient strategies for GAP.

First, those strategies increasing water availability, enhancing total irrigated lands and agricultural production are discussed.

IX.1. Enhancing Irrigated Lands and Agricultural Production

The first analysis of this section combines scenario analysis "*crop preference change after year 2000*" and "*rapid land transformation*" ("improvement scenario A"). Therefore, in this run, changing attitude in crop preference and a rapid transformation from rainfed farm systems are assumed. This improved scenario yields increased irrigated lands (ha), increased water delivery for individual farms (mm/year) and increased agricultural production (kg/year) for the commodities. The behavior of variables representing irrigation development are illustrated in Figure 9.1.

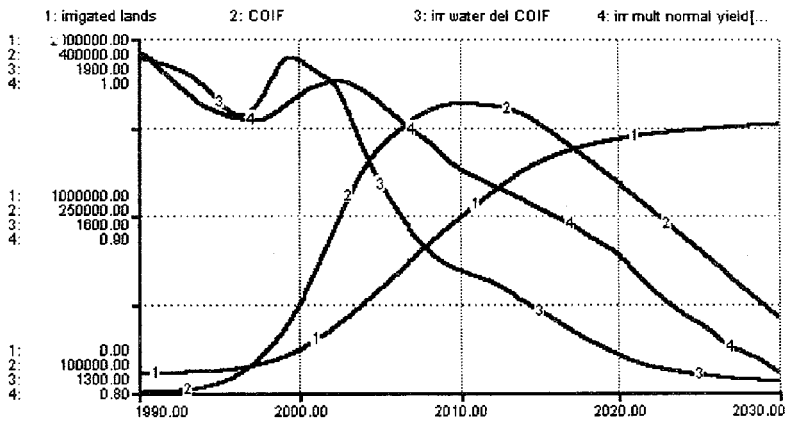


Figure 9.1. Irrigated lands and water availability in "improvement scenario A" .

According to this run, arable land use and enhanced agricultural production are illustrated in Figures 9.2 through 9.5. According to the base run, while cereals supply decrease as more lands are transformed to irrigated system, cotton supply stays the same and supply values of other products increase significantly. Also, as water delivery is increased, yields for the irrigated crops (kg/ha/year) are improved.

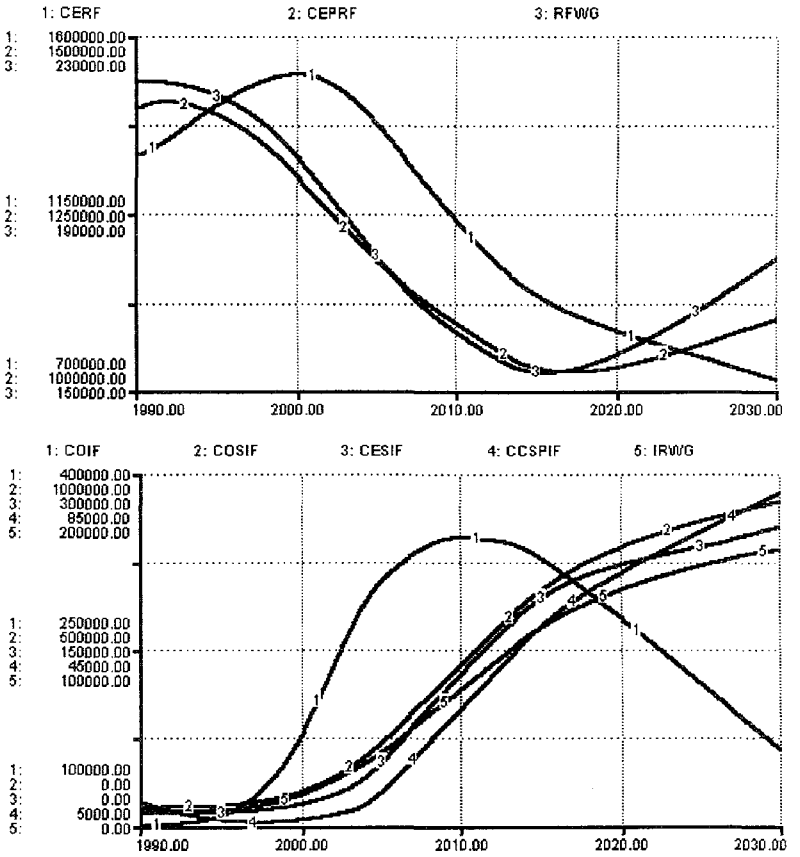


Figure 9.2. Arable land use in "improvement scenario A".

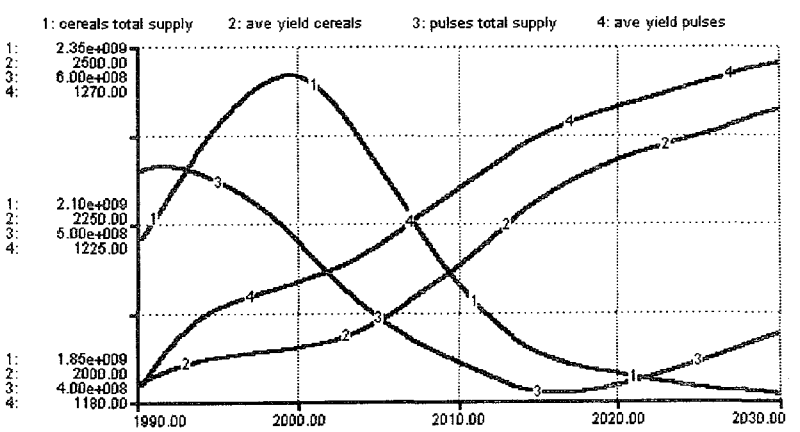


Figure 9.3. Cereals and pulses supply and yield in "improvement scenario A".

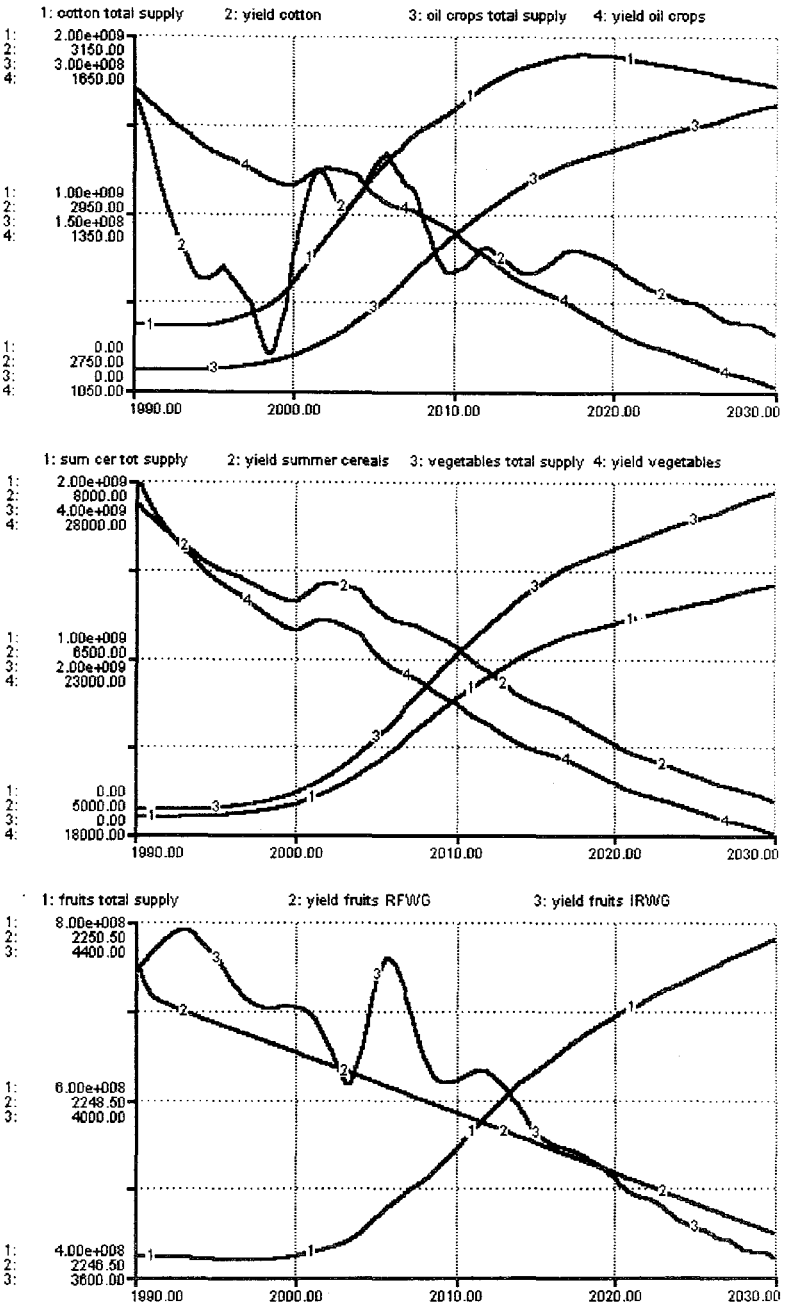


Figure 9.4. Cotton, oil crops, summer cereals, vegetables and fruits supply and yield in "improvement scenario A".

Also, by this scenario, as cotton monoculture (COIF) is taken under control after year 2010, average pesticide application rate decreases but increased cereals, pulses and vegetables cultivation on irrigated fields result in increased phosphorus material application (Figure 9.5.).

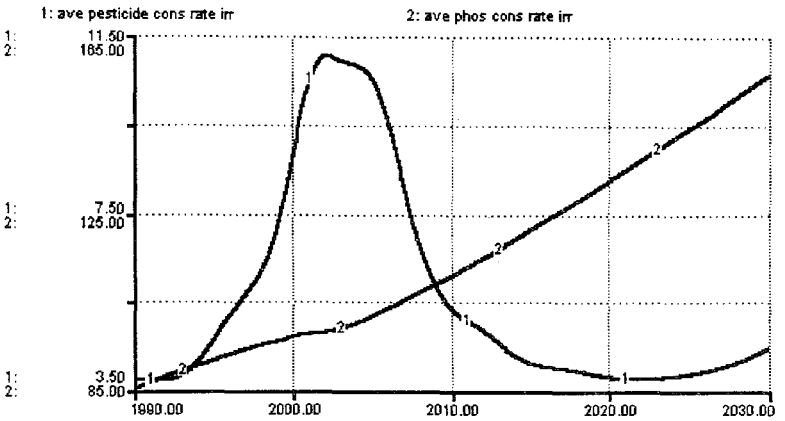


Figure 9.5. Average pesticide and phosphorus material application rate in "improvement scenario A".

"Improvement scenario A" can be integrated with higher hydropower production policy. If irrigation priority is dropped in "improvement scenario A" (combining policy "low irrigation priority after year 2000"), hydropower production can be increased without causing unacceptable limitations in irrigation development. The resulting behavior for water resources in "improvement scenario A" with increased hydropower production is illustrated in Figure 9.6.

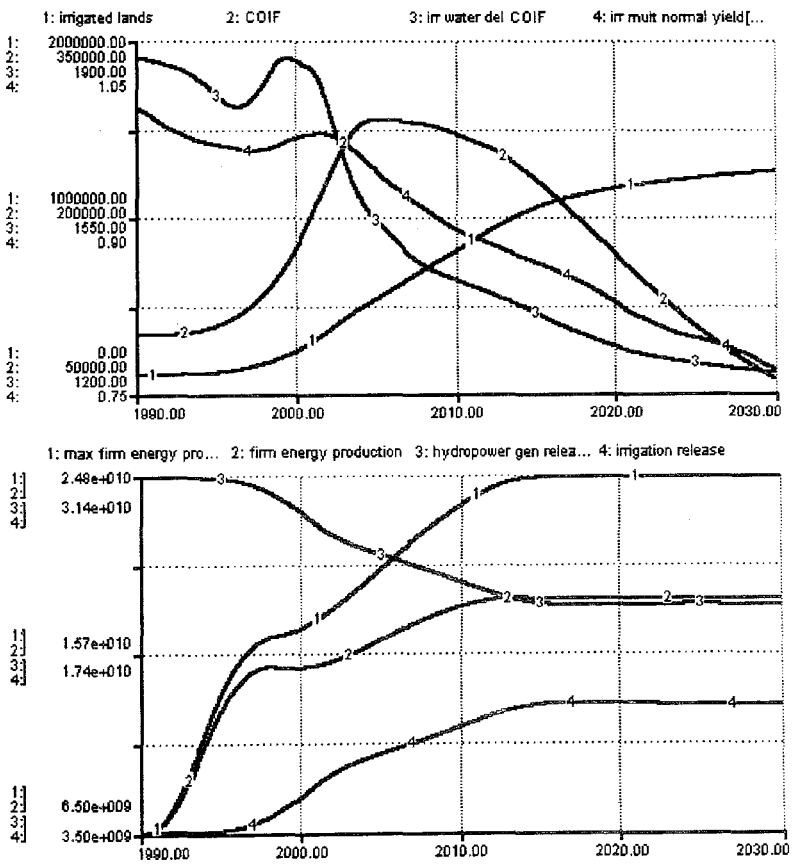


Figure 9.6. Water resources development in "improvement scenario A" with increased hydropower production.

IX.2. Preventing Land Degradation and Agricultural Pollution

"Improvement scenario A" provides enhanced irrigation development, enhanced agricultural supply and yields by decreased intensity of cotton cultivation and increased water delivery to individual farmlands. This scenario also prevents excessive average pesticide application on irrigated fields. But still, decreasing yields due to salinization and erosion inevitably increases fertilizer application rates. In this section, "improvement scenario B" is created in order to illustrate modified system behavior of "improvement scenario A" under salinization control and low pesticide resistance development (combining scenario "*low pest resistance building*" and policy "*salinization control*"). Also, in this scenario, support practice factor for erosion control on arable lands is decreased, so that, fertilizer application rates are further lowered. According to "improvement scenario B", there is not any significant change in total irrigated lands and arable land use when compared to "improvement scenario A" but, total agricultural supply and yields are further improved together with those variables representing land degradation and agricultural pollution. Salinization in soil root zone (mg/l), average pesticide application on GAP irrigated lands (kg/ha/year) and average fertilizer application rates (kg/ha/year) according to "improvement scenario B" is illustrated in Figure 9.7.

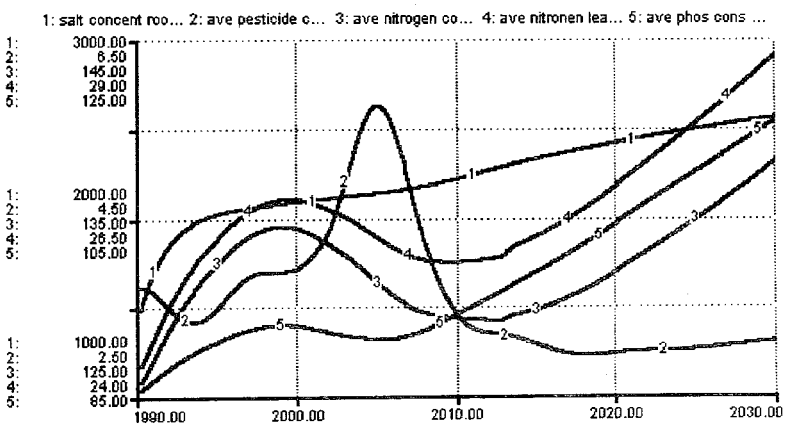


Figure 9.7. Land degradation and agricultural pollution in "improvement scenario B".

Further enhanced yields and agricultural supply quantities according to the improved environmental conditions are demonstrated in Figure 9.8.

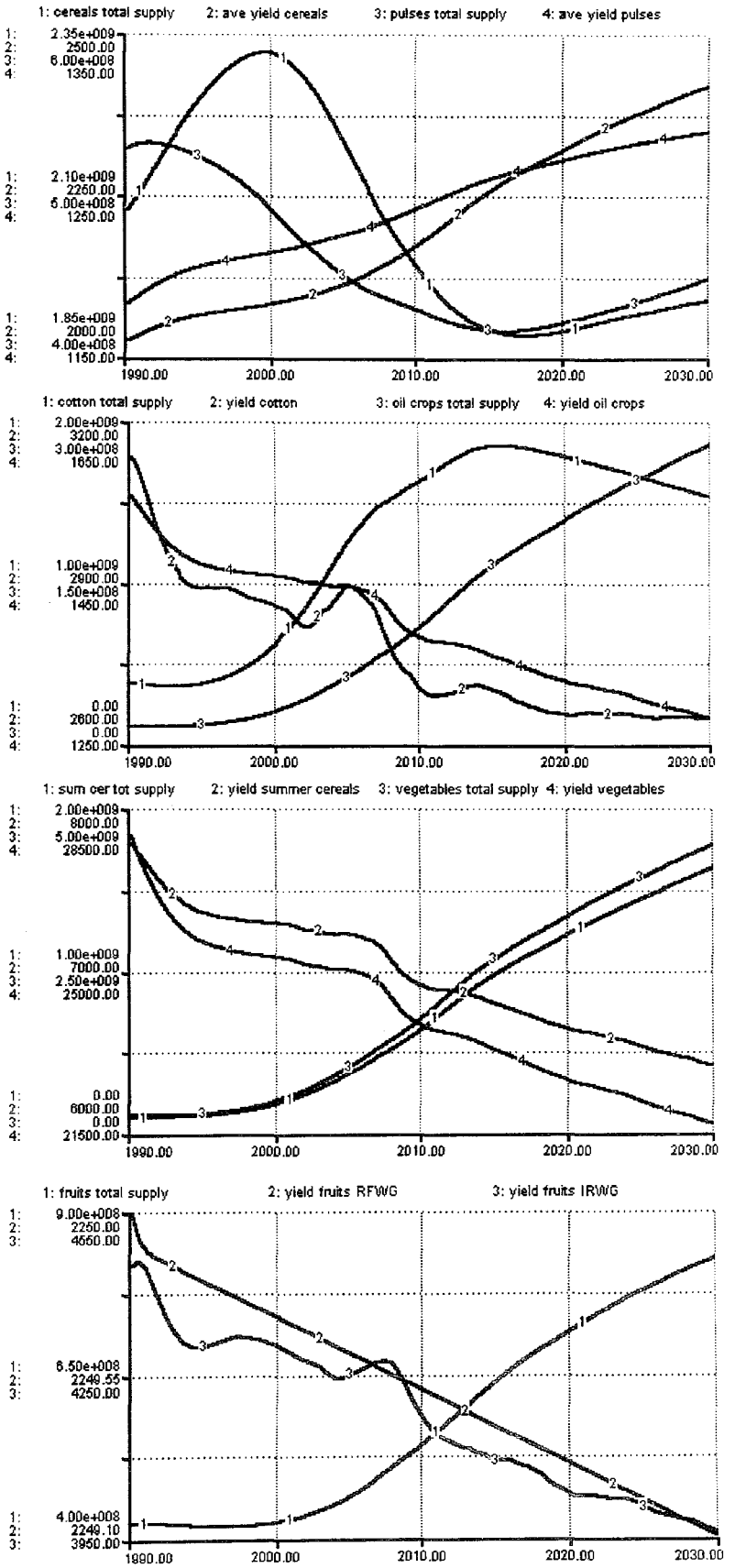


Figure 9.8. Agricultural supply and yield in "improvement scenario B".

IX.3. Rangelands Improvement

Up to "improvement scenario B", since profitability of crop production increases due to decreasing input costs and increased yields, animal husbandry on farmlands looses its relative advantage with respect to crop production. On the other hand, since rangeland destruction is still in process, livestock on rangelands continue declining together with rangeland quality. In this section, "improvement scenario C" is created by cobbining rangelands improvement and market interventions promoting animal husbandry (combining policies "*rangelands improvement*" and "*government promotes animal husbandry*"). Improved rangeland quality and improved livestock quantities according to "improvement scenario C" are illustrated in Figure 9.9. According to this scenario, crop production is relatively decreased since some portion of lands is allocated for fodder production but this is negligible when scale of increase in sheep on farmlands is considered.

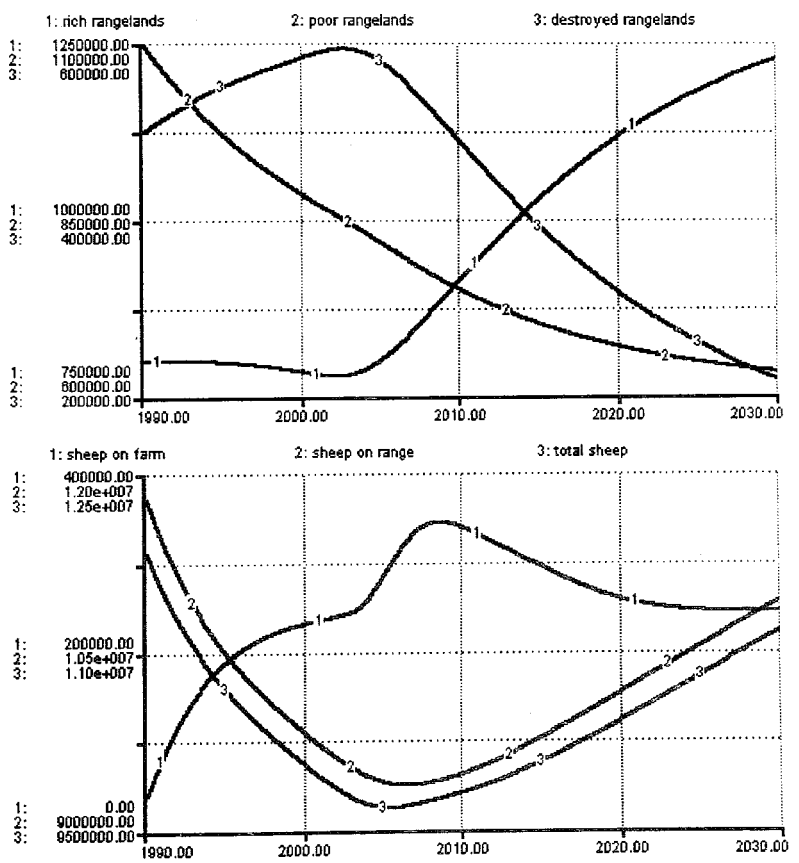


Figure 9.9. Rangelands and livestock in "improvement scenario C".

IX.4. Improved Urbanization

Last scenario integrates "improvement scenario C" with assumptions stated in sections VIII.1.3.1, VIII.1.3.2, VIII.1.4.2 and VIII.1.4.3. Therefore, "improvement scenario C" is integrated with *increased urban land priority*, *high industry initiation rates*, *decreased net birth rate and emigration rates* and the last scenario "improvement scenario D" is created. Also, this scenario assumes, increased portion of regional agricultural production is allocated as rawmaterial for agro-industries in GAP region. The modified behavior of variables related to population and food and job availabilities are illustrated in Figure 9.10. According to "improvement scenario D", all population parameters increase and regional emigration decreases by year 2000. Although population is increased, rural food availability and urban job availability are improved as a higher urbanization rate is achieved according to this run.

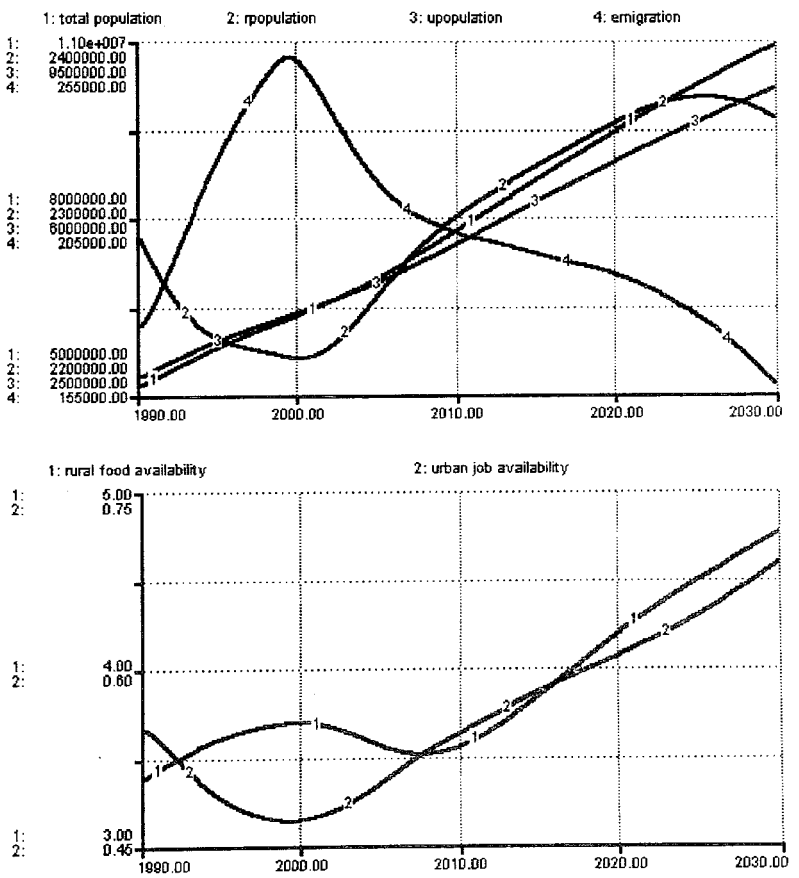


Figure 9.10. Population, rural food availability and urban job availability in "improvement scenario D".

Increased urban growth rate in "improvement scenario D" is demonstrated in Figure 9.11.

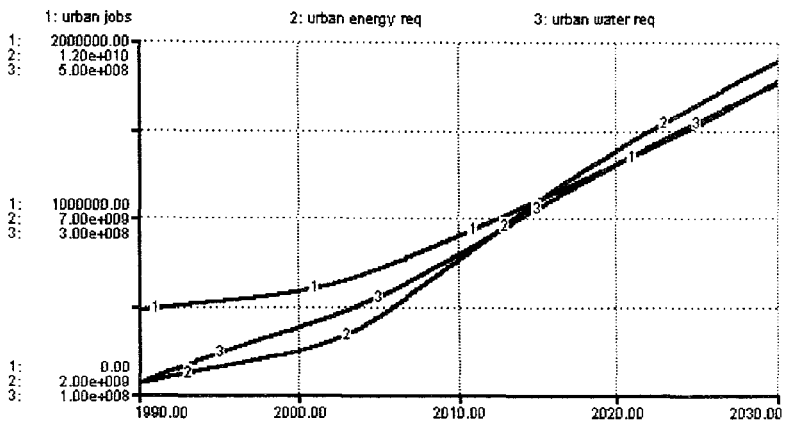


Figure 9.11. Urban growth in "improvement scenario D".

Enhanced urbanization means increased demand for agricultural products, which modifies water availability, land use, land degradation and agricultural pollution through increased second cropping percentages. Modified behavior for irrigated lands and water availability on individual farmlands in "improvement scenario D" is illustrated in Figure 9.12. When the new behavior is compared with "improvement scenario A", a slight decrease in total irrigated lands and a significant decrease in water delivery to individual lands is observed.

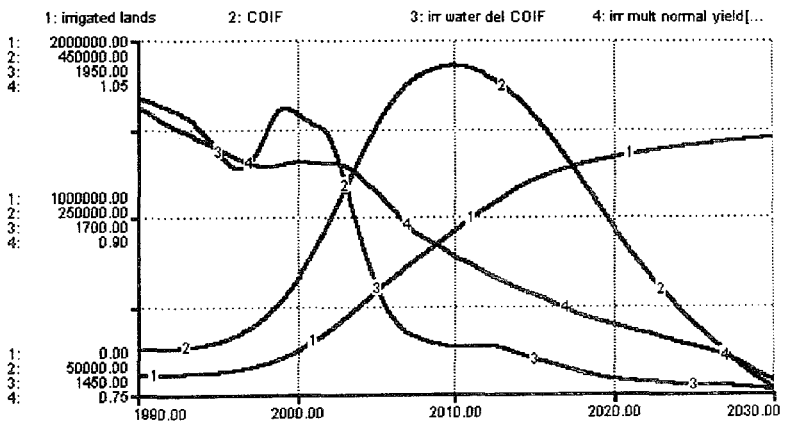


Figure 9.12. Irrigated lands and water availability in "improvement scenario D".

Changing water availability and increased demand for agricultural products also change the arable land use, when compared to "improvement scenario A" (see Figure

9.13.). High consumptive-use crop cotton monoculture is further inhibited and irrigated lands for cereals and pulses production is increased according to this new behavior.

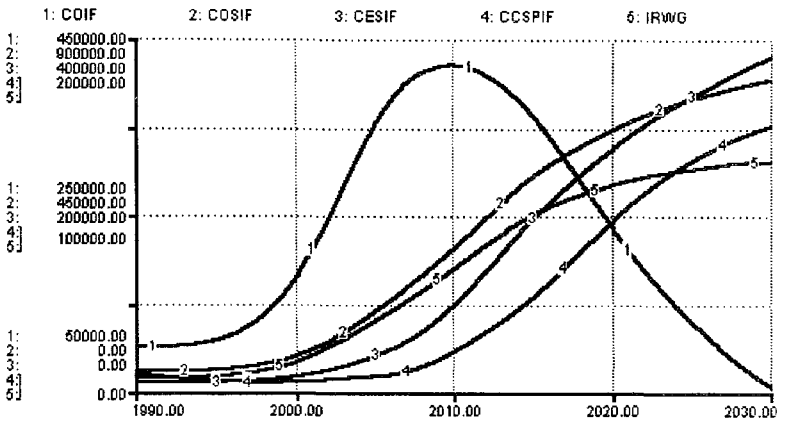


Figure 9.13. Arable land use in "improvement scenario D".

Also, increased second cropping on irrigated fields affects variables related to land degradation and pollution when compared with "improvement scenario B". According to the modified behavior on Figure 9.14., salinization, average pesticide application rates and average fertilizer application rates are slightly increased when compared to the "improvement scenario B" but this modification is not significant in scale.

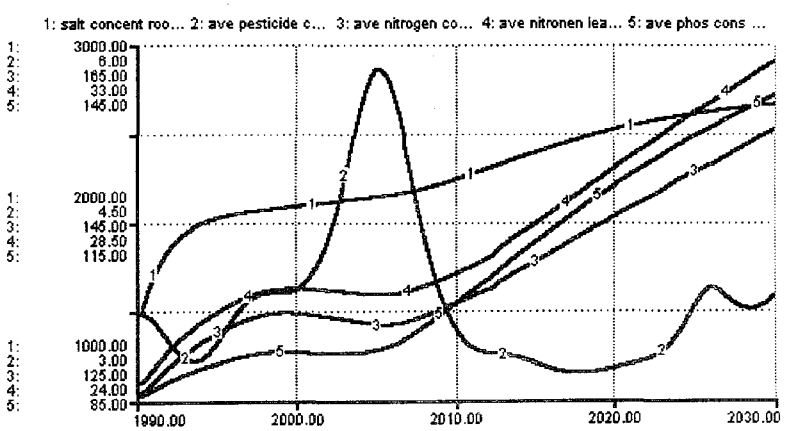


Figure 9.14. Land degradation and agricultural pollution in "improvement scenario D".

Though average yields are not affected in this scenario, because of changing land use on irrigated fields and increased second cropping, total supply for pulses, oil crops, summer cereals and vegetables are increased when compared to the "improvement scenario B" (see Figure 9.15.).

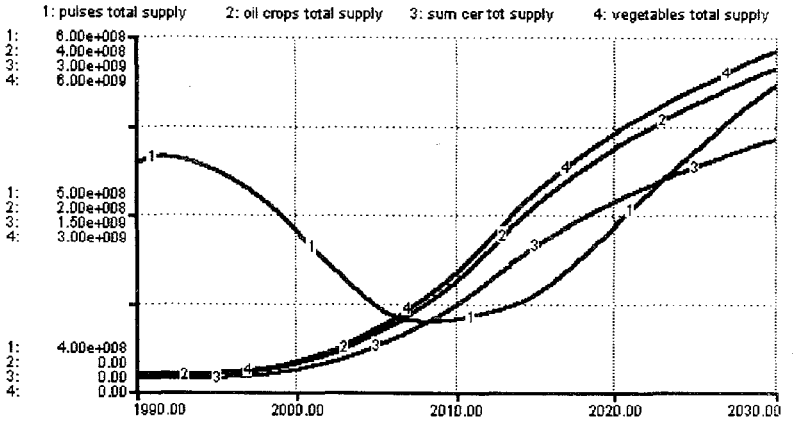


Figure 9.15. Modified agricultural supply in "improvement scenario D".

Another result of "improvement scenario D" is related to the effect of increased rural populatior on rangelands and forests conversion to arable lands. Increased pressure on rangelands and forests conversion to arable lands is illustrated in Figure 9.16. But here again, the scales of these modifications are not significant.

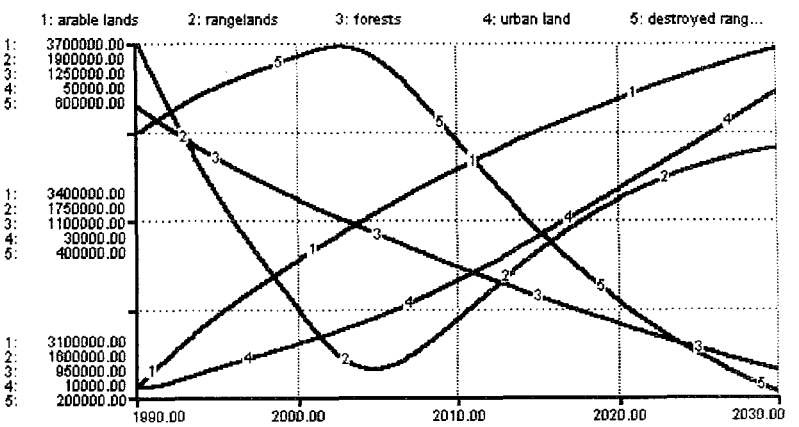


Figure 9.16. Land use in "improvement scenario D".

IX. CONCLUSION

In this research, those environmental problems of GAP region, related to agricultural modernization and integrated development are analyzed in a long term perspective. A dynamic simulation model, GAPSIM is developed for this analysis. GAPSIM is based on a systemic problem definition, which integrates selected aspects of natural, social and economic environment of GAP. According to this problem definition, water resources utilization, land use, agricultural production, land degradation, agricultural pollution, urbanization and population dynamics are integrated in a feedback structure.

The confidence in GAPSIM model is established through the standard validation procedure. First, model sectors are structurally validated according to those procedures suggested by the literature. Later, model behavior is calibrated with respect to the data available for years 1990-1998. During this procedure, model behavior concerning agricultural production, urbanization and population are behaviorally validated. Although sufficient confidence is established on model structure, because of lack of sufficient data concerning land use, land degradation and agricultural pollution, total model behavior may require further calibration, as more data become available in the future.

The reference behavior of GAPSIM points to many problems in regard to water resources, land use, land degradation, agricultural pollution, agricultural production, urbanization and population in the GAP region. According to the model reference run, increased intensity of the most evapotranspirant crop cotton on GAP fields causes significant water scarcity, which hinders development rate of irrigation into new acres. Also, water diversions to farmlands decrease and inhibit crop growth. On the other hand, increased monoculture cultivation of cotton leads to increased pest density on farmlands. Pesticide application rates gradually increase in order to sustain conventional yields.

In the long term, irrigation on GAP arable lands results in salt concentration increase in the soil root zone. Increasing the intensity of less evapotranspirant crops such as cereals and pulses slow down this process. Effective salinization control strategies can prevent excessive salt accumulation and waterlogging, but can not totally eliminate this

problem. Significant yield losses in salt-vulnerable crops are tried to be compensated by increasing use of chemical fertilizers which are cheap farm inputs. Similarly, yield losses because of soil erosion are reduced with the same mechanism without adding any significant burden on farm economies. But, this process results in increased nitrogen leaching from GAP irrigated lands.

According to the model reference run, urbanization rate in the GAP region can not satisfy demands of increasing population. Raw material unavailability for agro-industries again acts as a stabilizing factor for industrial development after 2020. Policies increasing the development rate of irrigation and enhancing agricultural production stimulate urban development rate. If such agricultural and environmental policies are integrated with high industry initiation, implying increased capital availability, changing attitudes in enterprising, subsidies etc., higher urban development rate yielding improved employment opportunities can be achieved. But, increased urbanization rate projected by GAPSIM is still far from being sufficient for the high population potential of the region.

Model reference run points to significant problems related to rangelands and animal husbandry. As livestock asset of the region is tied to the rangelands, overgrazing and declining rangeland quality results in decaying livestock quantity. Increased livestock on farmlands is far below the traditional quantities supported by the rangelands of the region. Also, under the conditions where rangeland destruction is in process, stimulation of animal husbandry through economic initiatives creates a temporary improvement in livestock quantity but prepares a future collapse through increased rangeland destruction rates. Therefore, rangeland improvement is a must for satisfactory results in livestock management.

Through the scenario and policy analysis related to "pest resistance building" and "salinization control", GAPSIM identifies two environmental factors active in crop pattern determination in the long term. First, an increase in pesticide requirement for cotton hinders cotton monoculture in favor of other summer crops and cereals. Second, salinization on GAP arable lands support production of salt resistant crops such as cereals and cotton, favoring cotton monoculture, thus elevating pesticide consumption rates.

Therefore, salinization control policy also helps decreasing the average pesticide application rate on GAP irrigated lands.

The scenario analysis related to "pest resistance building" reveals that, unless multi crop rotation systems are stimulated, pest management strategies based on the chemicals control in the market or on their field monitoring can delay the increase in pesticide application rates but can not eliminate this problem in the long term.

Two factors have considerable effect on water availability, arable land use, agricultural pollution and agricultural production. First, a significant improvement in system performance is achieved if the assumed "attitudes in crop preference" which create bias towards the traditional crops such as cereals, pulses and cotton are altered and crop rotations of new crops are stimulated. By this scenario, which implies improved marketing infrastructure for new crops and improved farm extension practices, intensity of the most evapotranspirant crop cotton and its monoculture is decreased. By the increasing availability of irrigation water, enhanced yields and higher irrigated lands are achieved. As cotton monoculture is hindered, average pesticide application rates are lowered and average salinization profile is decreased. All these processes result in increased regional agricultural production and profitability, which creates potential for improved urbanization rates.

Secondly, if all farmers are assumed willing to transform their rainfed farm systems whenever water is available, again, more lands are irrigated. This time, cropping intensity of the most evapotranspirant crop cotton is hindered as water delivery per individual farm is decreased. According to this scenario, although water delivery to individual farms is decreased, total agricultural production is increased, and similarly, a better performance pattern for pesticide application rates and soil root zone salinization is achieved. Both of these scenario analyses related to "attitudes in crop preference" and "rate of land transformation" imply democratization of irrigation through improved infrastructure and farm extension practices and have considerable positive effects on water availability, land use, land degradation and agricultural pollution as described in above paragraphs.

GAPSIM demonstrates individual effects of "traditional attitudes", environmental control and market interventions on system behavior. Therefore, integration of policies related to traditional attitudes, market and environment can be very effective in creating an improved system performance. For example, by the combination of scenarios and policies related to "attitude change" in crop preference, "rapid land transformation", "salinization control" and promotion of pulses production, water availability on individual farmlands and total irrigated lands increase. As salinization is controlled, increase in fertilizer application rates can be considerably avoided. As salt resistant crop cotton looses its relative environmental advantage, pesticide application rates decrease. Increasing the intensity of pulses stimulate multi crop rotation systems which facilitate effective control for pest density on farmlands. As irrigated lands are increased and environmental quality is improved, regional agricultural production significantly increases and creates potential for urban growth.

GAPSIM provides a dynamic simulation platform where several scenario and policy analysis concerning GAP environment can be executed. Through this research, many feedback mechanisms are identified which improve our understanding of GAP as a socio-environmental system. This initial version may be larger than necessary, involving some redundant model components. On the other hand, it probably misses some interactions, which would help in arriving at more realistic conclusions about agricultural production, nutritional levels and population dynamics. As future work, a minimized version of the model can be constructed, embodying the basic scientific theory, and being at the same time richer in its feedback conceptualization of the problem. Such a compact version of GAPSIM would be more useful for communicating the research and its conclusions concerning GAP and regional development process to scientific community and to policy makers.

APPENDIX: CD-ROM CONTAINING SOFTWARE

In this appendix, the contents of submitted CD-ROM at the back cover is explained. In this CD-ROM, a "read.me" text file in ASCII format, runtime version of STELLA software and the STELLA application file "GAPSIM.stm" are involved.

The "read.me" text file contains instructions for installation of the STELLA software runtime version. "GAPSIM.stm" application file is the computer model which involves model map and model equations. For installation of STELLA runtime version and application of "GAPSIM.stm", the minimum system requirements for WINDOWS/DOS are 486 CPU, 8MB RAM, a hard disk with 10 MB available space and WINDOWS 3.1 or higher.

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