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by

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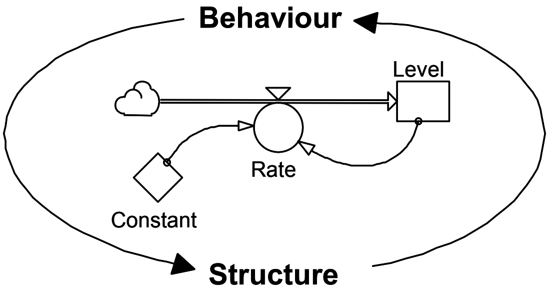

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SYSTEM DYNAMICS MODEL FOR INTEGRATED ENVIRONMENTAL ASSESSMENT OF LARGE SCALE SURFACE IRRIGATION

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ABSTRACT

Problems of irrigation systems performance and agricultural environment in large scale surface irrigation is analysed with a dynamic simulation model. Present model is a simplified and validated version of an original model built for the analysis of relevant problems in Southeast Turkey. Model consists of components representing farmlands, land and water development, irrigation and salinization, soil nutrients and pest dynamics. In addition, population dynamics and urban development are integrated. Model components include hypothesis on irrigation authorities' and farmers' decisions on irrigation release, water consumption, land transformation, crop selection and fertilizer and pesticide application. Structure and behaviour analysis of the model helps understanding the effects of represented decisions on the irrigation system performance and agricultural environment in the long term at regional level. Model structure can further be explored and custom tailored for educational and managerial use in specific case studies.

Keywords: big dams, surface irrigation, environment, production, population, decision rules, system dynamics.

I. INTRODUCTION

On fertile lands in semiarid regions, large scale surface irrigation facilitated by dam building has been a prominent regional and national development policy. In the past century, in global scale, more than 45000 large dams have been built to provide water for irrigated agriculture, domestic or industrial use, to generate hydropower or help control floods (WCD 2000). Expected benefits of hydropower and irrigation dams were high crop yields and varieties, agricultural modernization, rural welfare and regional development. Job creation and installation of an industry base with export capabilities were often cited as additional rationale for building dams (GAP-RDA 1990; Altinbilek 2002). However, the record of the existing dams have been rather appalling with many adverse social and environmental impacts which are documented in rich case studies (Goldsmith and Hilyard 1984; WCD 2000). These impacts have a far extend ranging from the immediate displacement of large populations and destruction of monumental cultural heritages to equity issues between different sections of the rural population and between different land holders with varying degrees of access to irrigation water supply. Such impacts together with other adverse effects on the ecology and environment today, create the basis of a strong opposition against big dams and centrally controlled large scale surface irrigation.

The focus in this paper is on the performance of big hydropower and irrigation dams and the impact of large scale surface irrigation on agricultural sustainability in systems perspective. Big dams are giant structures, nested systems of hydropower production, agricultural production, environment and markets. A global review of 52 large dams by World Commission on Dams reveal that, many hydropower dams show an overall tendency to fall short of power generation goals; large dams designed to deliver irrigation services have typically fallen short of physical targets; and one-fifth of irrigated land worldwide is affected by waterlogging and salinity due to dam-fed irrigation, which often means severe, long-term and often permanent impacts on land, agriculture and livelihoods (IRN 2002). Large scale irrigation projects target transformation of traditional agricultural systems into commercial systems. During this process, undesired crop patterns, shortfall in desired yields and unanticipated increase in agricultural chemical use are common problems coupled with the problems of irrigation systems performance (Mannion 1995), p. 262; (Goldsmith and Hilyard 1984).

Systems research in agriculture, focusing on the integrity of agronomic, economic and environmental factors in agricultural production are mostly in crop or farm level. The review provided by (Kropff, Bouma et al. 2001) supports this observation. The collection of research provided by (Teng, Kropff et al. 1997) includes examples of research on regional level but many of these studies either focus on single crops dynamics at a large scale or are only concerned about problems of land use. In this research we try to build a systemic understanding of the problems of large scale irrigation for public discussion, learning and management with a focus in the integrity of agronomic, economic and environmental components at regional level. Our methodology is System Dynamics (Forrester 1961), (Ford 1999), (Sterman 2000). We build a descriptive model of large scale surface irrigation systems at watershed level representing the dynamics of hydropower production, land development, agricultural production, pollution and demographics. The simulation model structure includes several hypotheses about the decision rules of irrigation authorities and farmers in water release, water use, crop selection and agro-chemicals consumption as well as basic physical processes of land transformation, water transport, salt accumulation, and nutrient and pest dynamics. Model experiments and behaviour analysis help exploring the reasons behind the weak performance of many large hydropower – irrigation systems observed in various case studies (Goldsmith and Hilyard 1984; WCD 2000).

Present model is a simplified and validated version of an original model built specific to an irrigation development project in Southeast Turkey (Saysel, Barlas et al. 2002). The boundary and details of the original model are significantly reduced to highlight and communicate the essential system structures and formulations responsible for the undesired system behaviour and validated against the original (Saysel and Barlas 2004). It embodies the fundamental scientific knowledge to serve as the basis of an integrated assessment but it lacks the details rendered unimportant for the model purpose by extensive analysis of the previous model. Model is calibrated with respect to data available from Southeast Turkey (GAP) to show its selected dyamics can be tuned against this specific case; details of validation is discussed in (Saysel and Barlas 2004).

Next we introduce the model structure discussing the elementary physical dynamics and hypotheses about decision rules. Then, the model reference behaviour is illustrated to highlight those potential problems of irrigation systems performance and agricultural environment simulated by the model. After that model behaviour response to well known management strategies and their limitations are illustrated gradually integrating the model components. In this section, a causal loop analysis of the model structure is developed to support understanding of model behaviour. Final section is a discussion on the use and benefits of system dynamics in the analysis of irrigation development problems.

II. MODEL DESCRIPTION

Model represents a low technology and low input settled agricultural system in mid latitudes where annual precipitation concentrates in winter seasons and a large water deficit occurs during summer. Winter cereals such as wheat and barley, and pulses such as lentil, bean and chickpea benefiting from the winter water surplus are the traditional crops which sustain regional population. Although mechanization is weak and primary inputs such as fertilizers, crop protecting chemicals and irrigation are rare and scarce, lands are fertile and traditional yields are sufficient both to sustain high population and to support national market. By introducing irrigation through canal structures, central authority enables the receivers to enhance their yields, to switch from traditional crops to industrial crops, and to increase their income by secure water supply. As irrigated farmlands develop, labour requirements also increase.

As the hydropower and irrigation structures are constructed, the water release capacity increases and farms begin to receive water. Water consumption on farmlands depends on water requirements of crops and the amount of water available to individual farmlands. Authorities centrally controlling the irrigation systems release water as a response to the water requirements of irrigation districts. Perennial irrigation increases the watertables and evapotranspiration of irrigation water release salt on farmlands, which can inhibit plant growth in the long term.

Modern agriculture require chemical fertilizers, basically inorganic N compounds to supplement crop nutrition requirements and a mix of chemical pesticides to suppress competing insect pests and weeds in the fields. For irrigation to achieve increasing yields chemical fertilizers and pesticides are the essential inputs to support decreasing water deficit. Unanticipated increase in fertilization and pest control requirements are common in many agricultural systems (Mannion 1995). Soil organic material loss due to tillage is usually compensated by increased use of cheap chemical fertilizers. Pesticide consumption can increase as pests develop resistance, as monocultures prevail and if integrated pest management is not a viable option because of several institutional and technological constraints.

The factors of irrigation system performance and agricultural environment effect crop yields and input requirements. Changing farm economic conditions create demand for alternative, more attractive crop patterns in the long term. Agricultural production is expected to form the basis of an industrial development. Increased agricultural production and input demand stimulates the installation of new industries, new jobs attract population from agriculture and urban growth goes along with agricultural development.

Model represents the systemic nature of these problems with 14 stock variables (differential equations) organized under seven sectors (model components): *farmlands*, *land-water development*, *irrigation-salinization*, *soil nutrients*, *pests*, *population*, *urban development*. Figure 1 illustrates these model components and material and information flows between them. Each model component includes hypothesis about physical dynamics and decision rules. All physical processes and decisions are represented in annual bases since the model is designed for long term analysis. Uncertainty in weather conditions and stream flows are not considered. Ultimate purpose is to analyze the effect of common management options about irrigation release, water consumption, drainage, fertilization, tillage and pesticides application on overall system behaviour. The system's behaviour is represented by hydropower production, land development, agricultural pollution, production and demographic movements. Next, we introduce the individual model components. Complete model equations are available from the author.

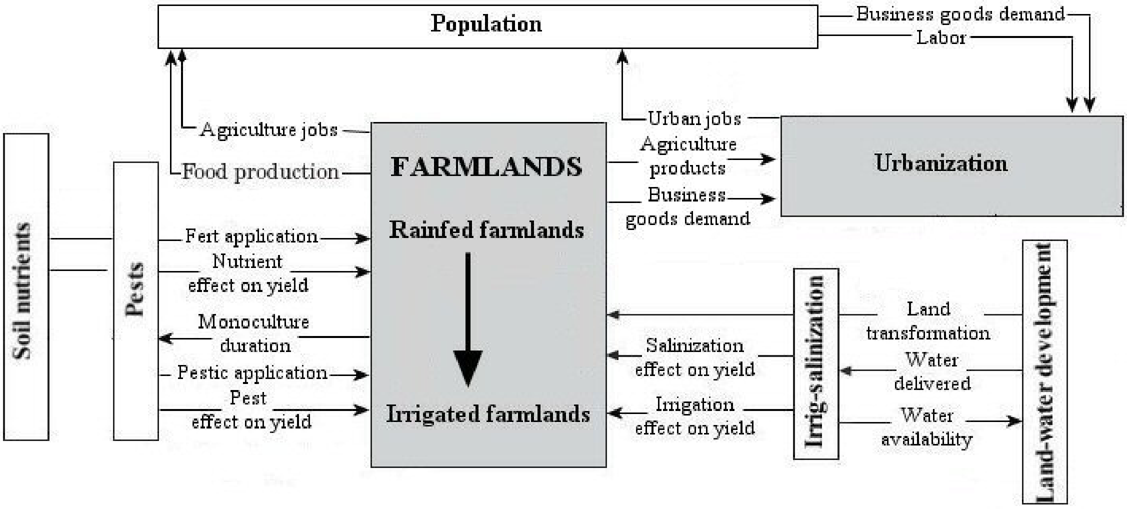

Figure 1. Model overview.

II.1. Farmlands

Farmlands model represents rainfed and irrigated farmlands aggregated under three stock variables (Figure 2). First stock variable *Rainfed Farmlands* stand for the traditional farms producing winter crops such as winter cereals and pulses either separately or based on rotations. The input of the production factors, pesticides and fertilizers are low, crops depend on precipitation, and yields are less reliable and are at moderate levels. Tillage is not intensive and on certain periods, fields are leaved on fallow to recover the soil moisture and nutrition contents. For the *Rainfed Farmlands*, the base values of the yield, fertilizer and pesticide application parameters average all these characteristics.

Monoculture Farmlands stand for the irrigated farmlands on which cotton is produced as a monocrop. Cotton represents the new prominent crop for the agricultural system, which has an increasing potential as the irrigations develop. The ease of marketing cotton as the prominent crop and ease of implementing monocultures especially by the large land holders can make it more attractive when compared to its alternatives. On the other hand, since it has a long residence time on the field over the seasons, cotton hardly lets farmers prepare their fields for second cropping (TOBB 1994).

Mixed Farmlands represent those irrigated farmlands which follow a balanced allocation of their land resources among cotton, winter crops and several summer crops such as summer cereals, oil seeds and vegetables. Again, the cotton, winter crop and summer crop yields, and fertilizer, pesticide and irrigation application parameters for *Mixed Farmlands* reflect the values obtained by averaging these characteristics.

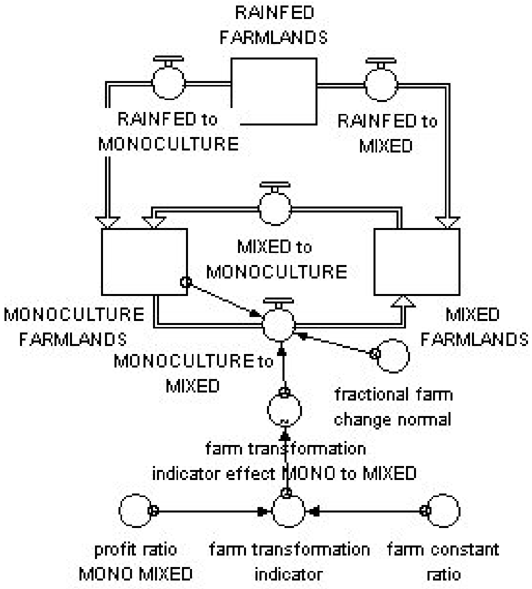

Figure 2. Stock flow structure of farmlands model.

Farmlands model calculates the profitability for each farmland stock under changing yield and input conditions. Yields change under varying environmental conditions of soil salinity, soil moisture content, nutrient levels and pest abundance on farmlands. Input application rates change based on factors of water availability, soil nutrient levels and pest abundance. Equation 1 shows the calculation of yields, for example for the *Monoculture Farmlands* (1):

yield cotton Monoculture = potential yield cotton x irrigation multiplier x salinisation multiplier x nutrient multiplier x pest multiplier

The hypotheses and formulations representing the change in input rates and individual effects of those inputs on yields (the multipliers) are described in the respective model components called *irrigation-salinisation*, *soil nutrients* and *pests*.

Rate of change from rainfed to irrigated farmlands depend on the availability of irrigation water. As new irrigation canals are constructed and as irrigation becomes available for more farmlands, more farmers switch to irrigation. This process and the formulation of this land flow are described in the respective model component, *land-water development*. The rate of change between monocultures and mixed farmlands is a function of their relative profitability and factors representing the ease of adoption of cropping methods. Below is the formulation of the flow from monoculture to mixed farming (2):

Monoculture to Mixed = Monoculture Farmlands x fractional farm change normal x farm transformation indicator effect Mono to Mixed;
farm transformation indicator effect Mono to Mixed = f(farm transformation indicator); $0<f<2; f(1)=1; f'<0;$
farm transformation indicator = profit ratio Mono to Mixed x farm constant ratio;
profit ratio Mono to Fixed = unit profit Monoculture / unit profit Mixed;
farm constant ratio = Mixed farm constant / Monoculture farm constant;

According to the farm transformation indicator, if none of the two farmlands is superior to the other, then the flows in both directions are driven by the constant, *fractional farm change normal*. Other parameters *Mixed farm constant* and *Monoculture farm constant* represent the ease of adoption of the alternative cropping methods and captures the factors in land transformation not endogenous to the model. Model behaviour can be tested with respect to different values of these parameters as well as several functional forms of *farm transformation indicator effect*.

Unit profits for the alternative farmlands are calculated by subtracting the annual incomes (yields multiplied by prices) from annual costs (inputs multiplied by prices) and dividing it to the size of the farmlands.

II.2. Land - Water Development

Land and water resources develop based on exogenous construction rate scenarios of hydropower and irrigation dams and irrigation canals. While experimenting with the model, the achievement of the project targets may be delayed, or the target levels themselves can be altered representing the factors not endogenous to the model. It is assumed that the irrigation release capacity linearly increases as the irrigation structures develop. The annual construction of irrigation structures accumulate in *Irrigated Farmlands Potential* (ha) and in *Irrigation Release Capacity* (m3/year) (Figure 3). Since land transformation from rainfed to irrigated farmlands is the farmers' decision, *Irrigated Farmlands Potential* is not irrigated unless the farmers decide to do so. This is formulated by the outflow *land transformation*, which drains the potentially irrigated farmlands and accumulates in the *Monoculture Farmlands* and *Mixed Farmlands* in the *farmlands model*.

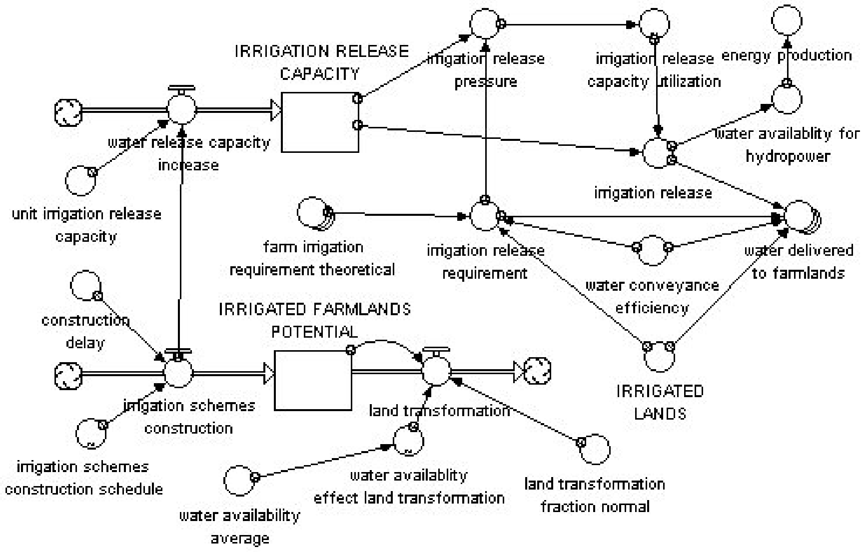

Figure 3. Stock flow structure of land–water development model.

Farmers' decision on land transformation is formulated based on the assumption that, the biggest incentive for farmers to switch to irrigation is water control. According to this assumption, if farmers perceive water scarcity on individual farmlands which imply insecure water supply to their fields, there is less incentive to switch to irrigation. As less water become available on farmlands, the expansion rate of the total command area of the irrigation project decreases. A similar hypothesis with respect to the effect of expensive and insecure groundwater supplies on irrigation command area is used by (Martinez and Esteve 2003) and research on farmers' response to insecure water supplies also suggests this hypothesis (Perry and Narayanamurthy 1998). This process is formulated as (3):

Irrigated Farmlands Potential = Integral (irrigation schemes construction – land transformation, Irrigated Farmlands Potential $_{t=0}$*);*

land transformation = Irrigated Farmlands Potential x land transformation fraction normal x water availability effect land transformation;

water availability effect land transformation = f (water availability farmlands); 0<f<1; f(1)=1; f′>0;

The constant, *land transformation fraction normal* stands for the fractional change when there is no water scarcity (*water availability farmlands* = 1); the *water availability farmlands* is calculated in the *irrigation-salinisation* model. This representation of farmers' land transformation decision allows experimenting with assumptions on fast and slow land transformation rates and on insensitive and sensitive response to water availability by *water availability effect land transformation*.

Water release policy of the irrigation authorities is also represented. Irrigation release decision is endogenous and based on *farm irrigation requirements* and *Irrigation Release Capacity*. It is assumed that as water demanded by the irrigated fields increase, this creates increasing pressure to utilize installed irrigation release capacity. *Irrigation release* formulation is as follows (4):

irrigation release = Irrigation Release Capacity x irrigation release capacity utilization;
irrigation release capacity utilization = f (irrigation release pressure); 0<f<1; f(0)=0; f′>0;
irrigation release pressure = irrigation release requirement / Irrigation Release Capacity;

This formulation of authorities' water release decision allows experimenting with loose and tight water release policies by *irrigation release capacity utilization*.

Last, energy production is calculated. Model does not represent seasonal fluctuations in stream flows; construction delays are exogenous. In the long term, energy production can deviate from its installed capacity because of water scarcity. The endogenous factor of water scarcity is the irrigation release as observed in some case studies (WCD 2000), p.51. As upstream irrigation release increase and less water become available for hydropower, the energy production levels decrease. Below is the formulation (5).

energy production = energy production maximum x water availability effect on hydropower;

water availability effect hydropower = f (water availability for hydropower); 0<f<1; f(1)=1; f′>0;

water availability for hydropower = (basin yield surface water – irrigation release + water recycled) / basin yield surface water;

Energy production maximum is the maximum firm energy production given that there is no irrigation release. *Water availability effect hydropower* represents the loss in energy production as a function of stream flow available for hydropower production. Here, this function is based on the estimates for GAP Irrigation Development Project (GAP-RDA 1997). *Basin yield surface water* is the average annual surface water supply in the watershed and *water recycled* is the water returning from agriculture either unused or through discharge, drainage and runoff (formulated in *irrigation-salinization* model).

II.3. Irrigation - Salinisation

Irrigation-salinisation model is based on (Saysel and Barlas 2001) but farmers' decision on how much to irrigate and crop yield response to *water availability for crops* and *Salinity Rootzone* are included. Since this is an annual model of integrated assessment, yield response to irrigation is not calculated on the basis of soil moisture content as in daily irrigation scheduling models (see for example, (Bala, Satter et al. 1988) and (Bala and Masuduzzaman 1998). The stock flow dynamics in annual bases does not allow the model to keep track of the soil moisture change subject to daily irrigation applications.

Each farmland has a specific *crop irrigation requirement* (crop's consumptive use minus effective precipitation, since precipitation is not an explicit variable in the model). *Farm irrigation requirement theoretical* is *crop irrigation requirement* divided by *farm irrigation efficiency theoretical* (Linsley, Franzini et al. 1992) where the efficiency term signifies the amount of irrigation water actually available to crops. Model represents farmers' irrigation application decisions based on *farm irrigation requirement* and *water delivered to farmlands*. Irrigation application decisions of the farmers are formulated as (6):

irrigation application = water delivered to farmlands x water utilization;

water utilization = f (water utilization pressure); $0<f<1$; $f(0)=0$; $f'>0$;

water utilization pressure = farm irrigation requirement theoretical / water delivered to farmlands;

This formulation allows experimenting with high and low water consumption attitudes of farmers by *water utilization* function. The amount of irrigation application modifies the farm irrigation efficiency. As more water is applied efficiency decreases, as less water is applied efficiency increases. Formulation is given below (7):

farm irrigation efficiency = farm irrigation efficiency theoretical x effect farm irrigation efficiency;

effect farm irrigation efficiency = f (irrigation application / farm irrigation requirement theoretical); $0.5<f<1.2$; $f(1) = 1$; $f'<0$;

farm irrigation requirement theoretical = crop irrigation requirement / farm irrigation efficiency theoretical;

While the theoretical farm irrigation efficiency stands for the efficiency term determined by technological constraints and therefore more rigid, actual efficiency is its modification according to farmers’ attitude. According to these formulations, consumptive or conservative attitude of farmers can affect water available to other farmlands and efficiency of irrigation on individual farmlands.

Then water availability for crops and its effect on yield is calculated (8):

irrigation water available for crops = irrigation application x farm irrigation efficiency actual

water available for crops = irrigation water available for crops + groundwater intrusion

irrigation multiplier = f (water available for crops / crop irrigation requirement); for winter crops 0.5<f<1; f(0)=0.5; f(1)=1; f′>0; for cotton 0.2<f<1; f(0)=0.2; f(1)=1; f′>0; for summer crops; 0.35<f<1; f(0)=0.35; f(1)=1; f′>0.

The *irrigation multipliers* represent the relative yields and are formulated benefiting from the relationship developed in (Hargreaves 1977) and used by (Perry and Narayanamurthy 1998). This formulation assumes the ratio of *water available for crops* to *crop irrigation requirement* as a proxy for moisture availability. This value includes capillary rise and groundwater intrusion. The adjustment in vertical axis considers the availability of precipitation.

Applied irrigation not available to the crops is *runoff* and *percolation* which recharges the groundwater. *Water available for crops* evapotranspirates through soil rootzone. Evapotranspiration releases salt while *percolation* flushes them. Portion of *percolation* is drained from the system and the rest contributes to *deep percolation* and elevates the *watertable*. Groundwater, if it exceeds *critical watertable depth*, intrudes rootzone and contributes to the *water availability for crops* and to the *salinity water available for crops* (Figure 4). Details of salt accumulation and groundwater processes and their feedback complexity are described in (Saysel and Barlas 2001).

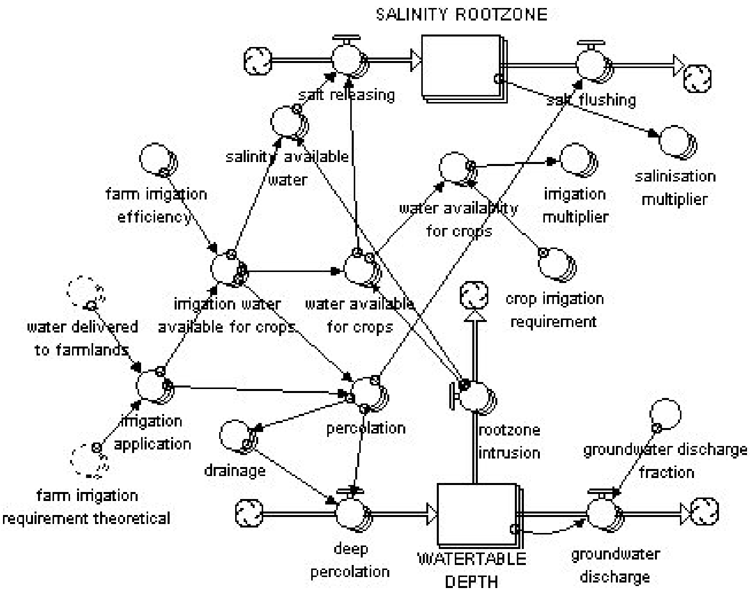

Figure 4. Stock flow structure of the irrigation-salinisation model.

Last, the effect of accumulated salt on crop yields is formulated by *salinisation multiplier* as a function of *Salinity Rootzone*. Salt tolerance values of crops are taken from (Foth 1990) and (Schwab, Elliot et al. 1993), converted by a conversion factor, 1 ds/m=670 mg/land, and then averaged for the crop mix represented as *winter crops*, *cotton* and *summer crops* in the model.

II. 4. Soil Nutrients

Soil nutrients model represents the macronutrients and stable soil organic matter dynamics which support crop growth. According to the model hypothesis, farmers tend to increase fertilizer application as they perceive nutrients deficiency. Increased fertilizer application masks decreasing soil fertility due to oxidation of soil organic matter by intensive tillage and loss of organic material by wind and water erosion (Mannion 1995), p. 237. Model consists of two stock variables (Figure 5). First stock variable *Nitrogen* stands for soil macronutrients essential for crop growth. Nitrogen is taken as a proxy for soil macronutrients in evaluating soil fertilization requirements of an agricultural system in the long term. It is the most important nutrient in soil organic matter from the economic standpoint. Crop yields are often directly proportional to the nitrogen released from organic matter. It is required in very large quantities and since inorganic nitrogen does not build up in soils but disappears through leaching, it is most likely to be the limiting agent in crop development (Foth 1990) p. 186. Second stock variable *Humus* stands for other soil attributes supporting plant growth such as micronutrients, structure and texture. This two stock representation of soil nutrient dynamics and its several formulations are based on (Bach and Saeed 1992) which analyzes food sufficiency in a national context.

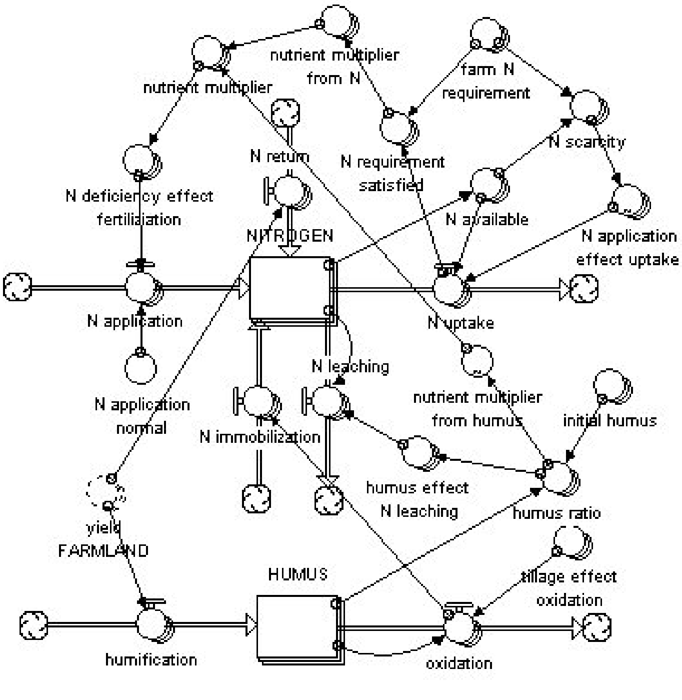

Figure 5. Stock-flow structure of the nutrients model.

Model calculates *potential N requirement* of crops by multiplying their *potential yield* with *crop N content* both for grain and residue components and subtracting the amount of nitrogen potentially fixed from the atmosphere. Data is aggregated from (Foth 1990) p. 188 and (USDA 2003). However, the maximum N requirements of the crops are limited by water availability. If irrigation water is scarce, crops fall short of their yield potentials and their nutrient requirement decrease. Model calculates the *farm N requirement* by multiplying *potential N requirement* with *irrigation multiplier*. Then, the *Nitrogen* dynamics and *N uptake* by crops is formulated (9):

Nitrogen = Integral (N application + N return + N immobilization – N leaching – N uptake, Nitrogen $_{t=0}$*);*

N uptake = N available x N application effect uptake;

N available = Nitrogen / N fraction available per year;

N application effect uptake = f (farm N requirement / N available); $0<f<1$; $f(0)=0$; $f(2)=1$; $f'>0$;

N leaching = Nitrogen x N leaching fraction normal x humus effect N leaching;

N fraction available per year is unity, means all N in the soil is potentially available to the crop. However, depending on the *N application effect uptake,* crop benefits from a part of this available N. Formulation of this effect allows experimenting with different assumption on farmers' fertilizer application attitude. Inappropriate placement and poor scheduling of fertilizer application would result in less uptake and more leaching, while an appropriate fertilization practice would result in more uptake and less leaching. *N leaching* is also influenced by *Humus*. As humus content decreases, leaching increases. This is formulated by *humus effect N leaching*.

Farmers' fertilizer application decision is based on the ratio of nutrient requirement satisfied. As farmers perceive N deficiency, they tend to increase the N application. The N application flow is formulated as follows (10):

N application = N application normal x N deficiency effect fertilization;

N deficiency effect fertilization = f (nutrient multiplier from N); $1<f<2; f(1)=1; f'<0;$

The *nutrient multiplier from N* is a function of *N uptake*. The overall affect of nutrient deficiency on yields is *nutrient multiplier*, which is obtained by multiplying *nutrient multiplier from N* and *nutrient multiplier from Humus* which is a function of *Humus*. The *N application* formulation allows experimenting with farmer response to observed nutrient deficiency by *N deficiency effect fertilization*. A consumptive response or a conservative response can be tested.

Humus dynamics is represented in (11):

Humus = Integral (humification – oxidation, $Humus_{t=0}$*);*
humification = yield x fractional crop residue x residue return fraction x humified fraction;
oxidation = Humus x oxidation fraction normal x tillage effect oxidation;

The tillage effect oxidation allows experimenting with alternative tillage effects on *Humus* oxidation. While conservation tillage can lead to reduced oxidation rates, traditional tillage can lead to higher. Finally, as the *Humus* decreases, *N leaching* from the soil increases. This is formulated in (12):

Humus effect leaching = f (Humus / initial humus); $1<f<3; f(1)=1; f'<0;$

Nonlinear formulations and model constants are adopted from (Bach and Saeed 1992).

II. 5. Pests

Pesticides model is a simple representation of pest dynamics and farmers' response to changing pest density on their farmlands. It incorporates the long term effects of chemical pesticides on target pest resistance building as identified by case studies and theoretical work

(Pimentel 1991; Pimentel and Greigner 1997; Begon, Townsend et al. 1998) p. 633-634. Increased monoculture durations assumed to increase the equilibrium abundance of pests (Begon, Townsend et al. 1998) p. 651. Also, regardless of their environmental effects and externalities that they create, farmers are assumed to increase pesticide application rates if they perceive an increase in pest density in their farmlands (Wilson and Tisdell 2001). Model consists of two stock variables, *Pest Density* and *Pesticides Effect Resurgence and Resistance* (Figure 6).

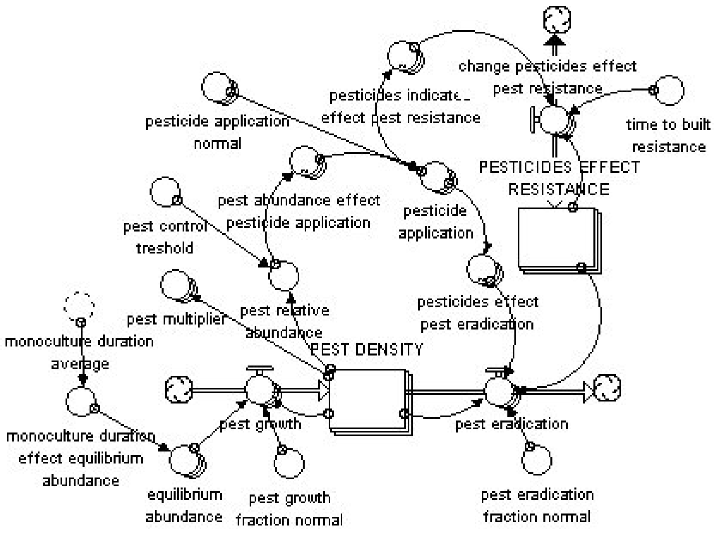

Figure 6. Stock flow structure of the pest model.

Pest Density is an aggregation of insect and weed pests acting on the farmlands and competing with and limiting the growth of crops. It increases by *pest growth* and decreases by *pest eradication*. *Pest Density* can increase up to its *equilibrium abundance* level if pests are not eradicated by pesticides. This is formulated by the logistic growth function. *Pest eradication* is a function of *pesticides effect on pest eradication* and *pesticides effect on resistance*. The formulation is (13):

Pest Density = Integral (pest growth – pest eradication);

pest growth = Pest Density x pest growth fraction normal x (1 – Pest Density / equilibrium abundance);

pest eradication = Pest Density x pesticides effect pest eradication x Pesticides Effect Resistance;

pesticides effect pest eradication = f (pesticide application ratio); f(0)=1; f′>0;

pesticide application ratio = pesticide application / pesticide application normal;

pesticide effect resistance = Delay (pesticides indicated effect resistance, time to build resistance);

pesticides indicated effect resistance = f (pesticide application ratio); f(0)=1; f′<0;

In these equations, *pesticides effect pest eradication* and *pesticides indicated effect resistance* allow experimenting with different assumptions on pesticide effects. Alternative chemical pesticides can have direct effects on varying degrees on pest eradication. Similarly, alternative chemical pesticides can have varying effects on pests' resistance i.e. can be more target-specific. However, no matter which category of the modern chemical pesticides are being consumed, unless integrated pest management is a viable option, newer and better pesticides can postpone or reduce these effects but they are most unlikely to uncover them (Begon, Townsend et al. 1998) p. 639. Therefore the model assumptions on pest eradication and pest resistance remain valid. In the above formulation, *pesticide effect pest resistance* is a delay function of the indicated effect. This allows experimenting with alternative assumptions on *time to built resistance*. These phenomena can occur soon or late.

The pest dynamics in the model is calibrated according to the equilibrium conditions such that, if no pesticide is applied, *Pest Density* stays at their *equilibrium abundance*. If *pesticide application normal* is applied and there is no long term effect on pest resistance, *Pest Density* stays at its desired level, the *pest control treshold*.

Pesticide application decision is based on the *Pest Density*. The formulation is (14):

pesticide application = pesticide application normal x pest abundance effect pesticide application;

pest abundance effect pesticide application = f (Pest Density / desired pest density); f(0)=0; f′>0;

Alternative functional forms of *pest abundance effect pesticide application* allow experimenting with consumptive or conservative increases in pesticide application as a response to changing *Pest Density*. The *pest multiplier* affecting the yields is formulated (15):

pest multiplier = f (Pest Density / Equlibrium Abundance); f(0)=1; f′<0;

The equations show that all the inputs to the nonlinear formulations (like the *pest multiplier*) are normalized, i.e. dimensionless. None of these functional forms are certain but are subject to extensive experimentation based on various assumptions. For all such uses, model behaviour sensitivity to these formulations is tested. The functional forms for pesticide-pest relationships and pest-yield relationships are inferred from discussions and illustrations in (Begon, Townsend et al. 1998) p. 624.

Last, according to the general knowledge, increased monoculture durations create uninterrupted resources especially for the weed pests on which their population levels can build up. Model represents this hypothesis by calculating *equilibrium abundance* of pests in monoculture as a function of *monoculture duration average*. Formulation is (16):

equilibrium abundance = reference equilibrium abundance x monoculture duration effect equilibrium abundance;

monoculture duration effect equilibrium abundance = f (monoculture duration average / monoculture duration normal); f′>0;

monoculture duration average = Monoculture Farmlands / Monoculture to Mixed;

Above formulation represents one of the most crucial model assumptions which drive the pest dynamics.

II.6. Population

Population model represents the population living in rural areas engaged in farming and the population living in urban sites engaged in formal and informal economic activities aggregated in two stock variables, *Rural Population* and *Urban Population*. *Rural Population* increases by *rural net births* and decreases by *rural emigration* and by *in-regional migration*. *Urban Population* increases by *urban net births* and by *in-regional migration* and decreases by *urban emigration* (Figure 7). These formulations of flows restrict migration to rural areas and migration to urban centres from outside the region.

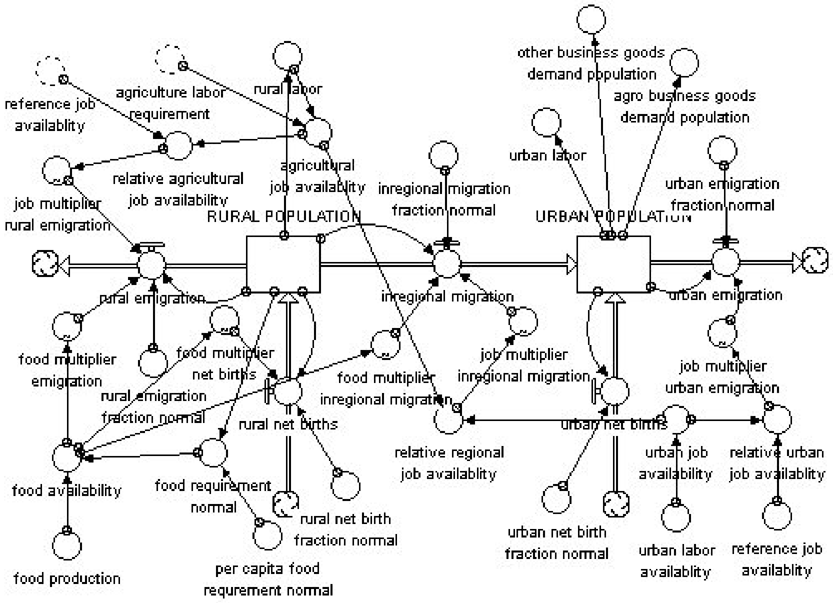

Figure 7. Stock-flow structure of the population model.

In this aggregated view of population dynamics, the birth and migration rates are formulated based on the feedback view of the population models in past studies, (Forrester 1969), (Forrester 1971), (Meadows, William W. Behrens et al. 1974) and (Saeed 1994). The basic idea behind this feedback view is that, over long time horizons, treating the births, deaths and migration as exogenous is an unrealistic oversimplification, because, factors such as nutrition, the material standard of living, crowding and pollution all depend on the size and the wealth of the population and in turn, create a huge number of feedbacks on population flows.

In this model, two factors, nutrition and wealth are considered in formulating the population flows. *Agricultural job availability* and *food availability* in rural areas and *industrial job availability* in urban sites are the proxies for nutrition levels and welfare of the population living in villages and urban centres respectively. Decreased nutrition levels increase infant deaths and vulnerability to diseases and the net effect is reduced life expectancy. In the model, the effect of nutrition on life expectancy is reflected by *food multiplier net births*. Nutrition is also a driving factor on emigration rates. Food shortages and malnutrition stimulates emigration. Model reflects this factor by the variables *food multiplier emigration* and *food multiplier in-regional migration* which affect the emigration and in-migration rates respectively.

Irrigated agriculture is supposed to increase regular agricultural labour requirement since the intensity of harrowing, ditching, irrigating, fertilizing and weeding are expected to increase together with other labour requiring economic activities and this is considered to be a major counterforce on emigration rates (Chambers 1988), (GAP-RDA 1988). In the model, as the irrigations develop, labour requirement changes and labour availability affects the emigration rates of rural population. This factor is formulated by *job multiplier on rural emigration*. Similarly, following the classical formulations of (Forrester 1969) and other studies of urban dynamics, the availability of jobs in cities relative to the job availabilities in alternative attraction points stimulate the migration rates. This hypothesis is formulated by *job multiplier urban emigration*. Below is an exemplary formulation for population flows (17):

Rural Population = Integral (rural net births – in-regional migration – rural emigration, Rural Population t=0);
rural emigration = Rural Population x rural emigration fraction normal x food multiplier emigration x job multiplier rural emigration;
food multiplier emigration = f (food production / food requirement); $1<f<5$; $f'<0$;
food multiplier rural emigration = f (agricultural job availability / reference job availability); $0<f<3$; $f'<0$;

Urban net birth fraction is set constant, because within the boundaries of the model, there is not any endogenous hypothesis about the driving forces on life expectancy and birth rates in urban sites. Such a hypothesis would require explicit formulations of capital investments, capital and material standard of living which in turn would affect the birth rates and life expectancy.

II. 7. Urban Development

Urban development model aggregates all agro-business units under the stock variable *Agro Business Structures* and all other business units under *Other Business Structures*. Both stock variables increase by *business initiation* and it decreases by *business demolition* (Figure 8). Similar to the population model, urbanization is modelled based on the feedback view of past urban dynamics studies (Forrester 1969; Alfeld and Graham 1976). For instance, *agro business initiation* is a function of u*rban labour availability* and *agricultural goods availability* (availability of goods supplied from agriculture to be processed by agro business) whose values in turn, depend on the size of *Business Structures*. Agro business demolition is a function of *agro business goods availability* (goods processed by the agro business relative to its demand), which in turn depends on *Agro Business Structures* size. Similarly, other business initiation is a function of *urban labour availability* and *other business goods availability* (goods produced by other business relative to its demand). Demand for agro business goods depends on agricultural development and population. Demand for other business goods depends on population and agro business units. Growth in agro business stimulates other business structures by increasing the demand for their products. Formulations are not provided but available in the Appendix.

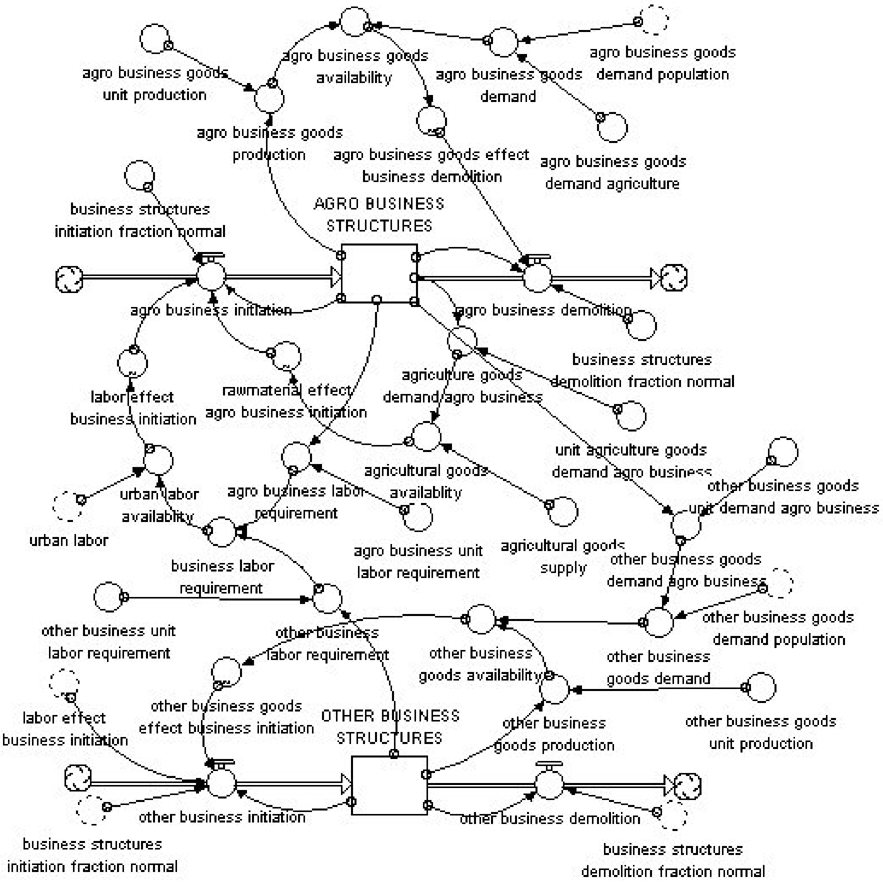

Figure 8. Stock flow structure of the urbanization model.

III. MODEL REFENCE BEHAVIOUR

Because model validation is discussed in (Saysel and Barlas 2004), we proceed with the model reference behaviour. The reference behaviour is illustrated to highlight the potential problems of irrigation system performance and agricultural environment simulated by the model (Figure 9). Reference behaviour is based on an exogenous land and water development scenario where hydropower production is expected to reach 27000 GWh/year without and 22000 GWh/year with upstream irrigation release, and irrigated lands are expected to reach 1.7 Mha within next 25 years. As the construction of physical structures take start, *energy production* (Gwh/year) and *irrigated lands* (ha) increase but both of them fall short of target since the water consumption on farmlands is above the project expectations. As irrigated lands increase the *ratio of irrigation release* to total basin yield (fraction of basin yield) also increases. In the fields average *yield loss due to water scarcity* (fraction of potential yield) first decreases but then continually increases.

The major reason for the underperformance with respect to energy and irrigation targets is the bias towards water consumptive monoculture in the emerging arable land use pattern. As water becomes available, farmers switch from rainfed to irrigated farm system. While *rainfed farmlands* (ha) decrease, the two irrigated fields, *monoculture farmlands* (ha) and *mixed farmlands* (ha) increase, however monocultures constitute about half of the total irrigated fields, which is a considerably high ratio.

As fields are irrigated, evapotranspiration and ground water elevation results in salt accumulation. As *rootzone salinity* (mg/l) increases, this favours cotton monocultures as cotton is a salt tolerant crop. Meanwhile, nutrient deficiency on all farmlands is being compensated by increasing chemical fertilizer consumption resulting in increasing average *nitrogen leaching* (kg/ha/year). The bias towards monoculture farm activity increases the need for pest control and average *pesticide application* (kg/ha/year) continually increases.

Agricultural production shifts from food grains to cash crops and urbanization accompanies agricultural development. As more agricultural products become available and more agricultural production factors are demanded from the industry, business structures increase. As a result, while *rural population* (capita) migrates to cities and decreases, *urban population* (capita) increases. *Food availability* (rural – fraction of food requirement) first increases as people fast migrate to cities but then levels off since grain production is decrease. Last, the increase in the *urban job availability* (ratio of jobs to labour) is balanced by emigration to cities and is not significantly improved.

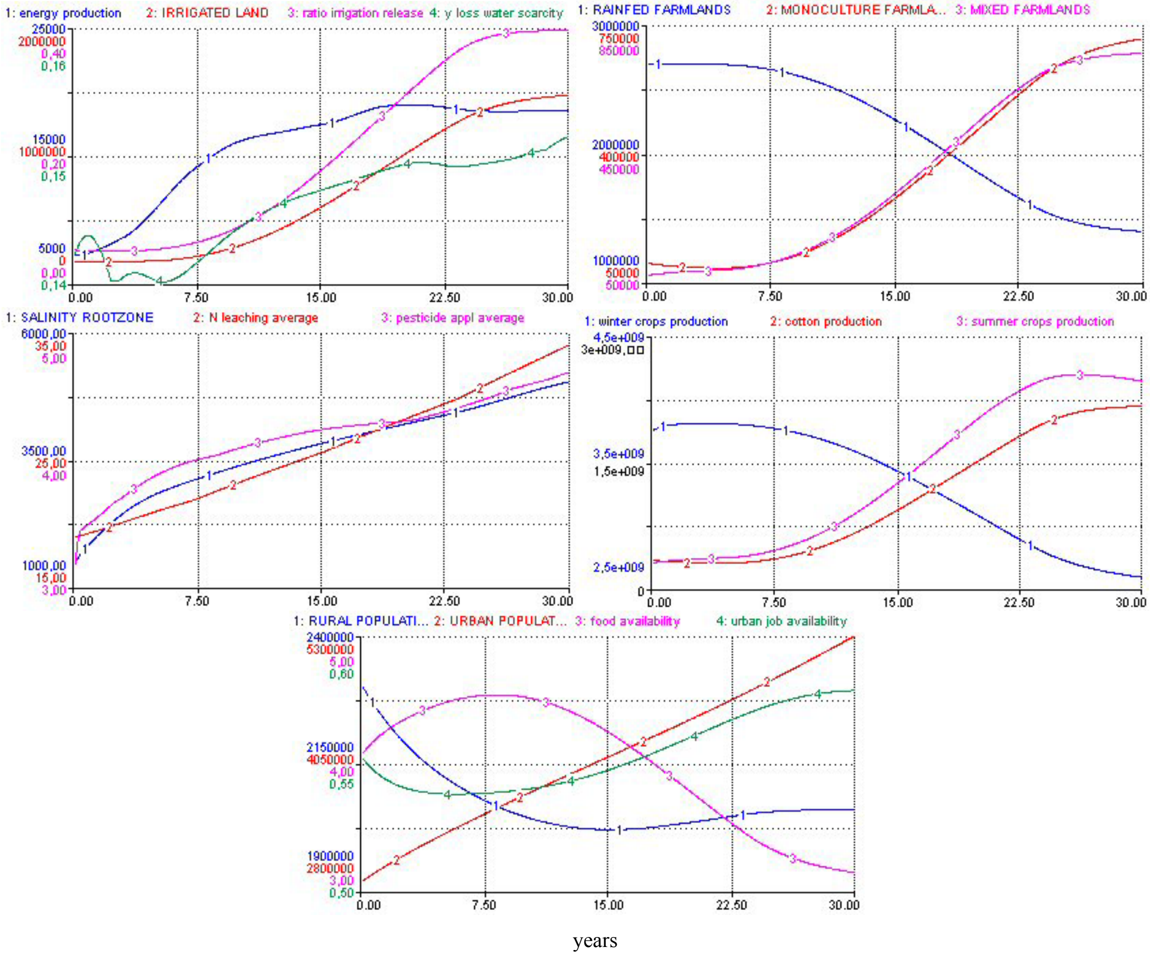

Figure 9. Model reference behaviour.

IV. MODEL ANALYSIS

To increase our understanding of the integrity of the processes represented by the model, we develop a feedback view of the model structure. Model behaviour response to well known management strategies and their limitations, effect of agro-environmental factors on irrigation system performance and effect of land use on agricultural environment are discussed. Since the structure behaviour analysis of the model is not trivial, we follow a stepwise approach gradually introducing different model components into the larger picture.

IV.1. Feedback View of Land - Water Development and Irrigation

First, to analyse the integrity of farmland use, energy production, irrigation and land transformation processes represented by *farmlands*, *land-water development* and *irrigation-salinization* models, we present a feedback view of water release (Decision I – irrigation authorities), irrigation application (Decision II - farmers) and land transformation (Decision III - farmers) decisions (Figure 10).

Total *irrigation release requirement* of the system increase either by increased *total irrigated farmlands* or by relative increase in *Monoculture Farmlands* when compared to *total irrigated farmlands*. Increased irrigation release requirement creates higher pressure to utilize existing release capacity; *irrigation release* increase (D1), *water delivered to farmlands* and the *average water availability* rise. This encourages *land transformation* (D3) and irrigated lands become more than they would have been if the transformation rate had not increased. Since this would further increase irrigation release requirement, more irrigation release and higher land transformation rates are expected. But this development is constrained by the physical limits of the system, *Irrigation Release Capacity* and *Irrigated Farmlands Potential* which gradually increase in time depending on the exogenous irrigation schemes construction scenario. Therefore, this self reinforcing loop (positive feedback – R1, the most outside loop) between irrigation release requirement and land transformation is active, only if there is available capacity.

Faced by a certain *irrigation release pressure* (total irrigation release requirement / irrigation release capacity) if irrigation authorities follow a loose release policy (D1=loose), *water delivered to farmlands* increase, *average water availability* rise, this encourages *land transformation* and irrigated lands become higher than they would have been had the land transformation did not increase. Therefore, an effect of loose release policy is fast land development, and increased irrigated lands if there is capacity available (R1). A second implication of loose release policy (D1) is increased *irrigation application* and higher *water availability for the crops*. Increased crop water availability favours all the crops but the most water demanding ones benefit more than the others. Since cotton is the most water demanding crop, increase in cotton yields would be relatively high than the winter and summer crops, this will relatively favour the monoculture farmlands and the net land flow from monoculture farmlands to mixed farmlands will decrease. Relative size of monocultures compared to mixed farmlands will be higher than it would have been if net flow from monocultures to mixed farmlands had not decreased. A consequence of this is increased monoculture to total ratio and an increase in irrigation release requirements. Then if there is capacity available, irrigation release can further increase, closing another reinforcing loop (R2). A third and an immediate effect of loose release policy is reduced hydropower production, because, as irrigation release increases, less water becomes available for hydropower production and energy production decreases.

Definite amount of water delivered to their farmlands, if farmers irrigation attitude is consumptive (D2=consumptive), first, average water available in the system decrease, and land development slows down. Second, more water becomes available for crops on the irrigated farmlands, relatively favouring monocultures.

Given definite water available in the system, if land transformation is less sensitive to average water availability (D3=insensitive), land transformation is faster; irrigated lands become higher than they would have been.

All these processes are either constrained by the physical limits of the system (irrigation release capacity and irrigated farmland potential) as illustrated by the reinforcing R loops, or balanced by negative feedback loops. For instance, any increase in total irrigated lands is balanced by a decrease in water delivered to farmlands, decreasing average water availability and reducing land transformation rate (negative feedback - B1). Any increase in the relative size of monocultures is balance by increased irrigation release requirement and decreased water delivered to individual farmlands (because water is appropriated by individual farmlands as a fraction of total irrigation release requirement), less irrigation application and conditions relatively favouring mixed farmlands (B2).

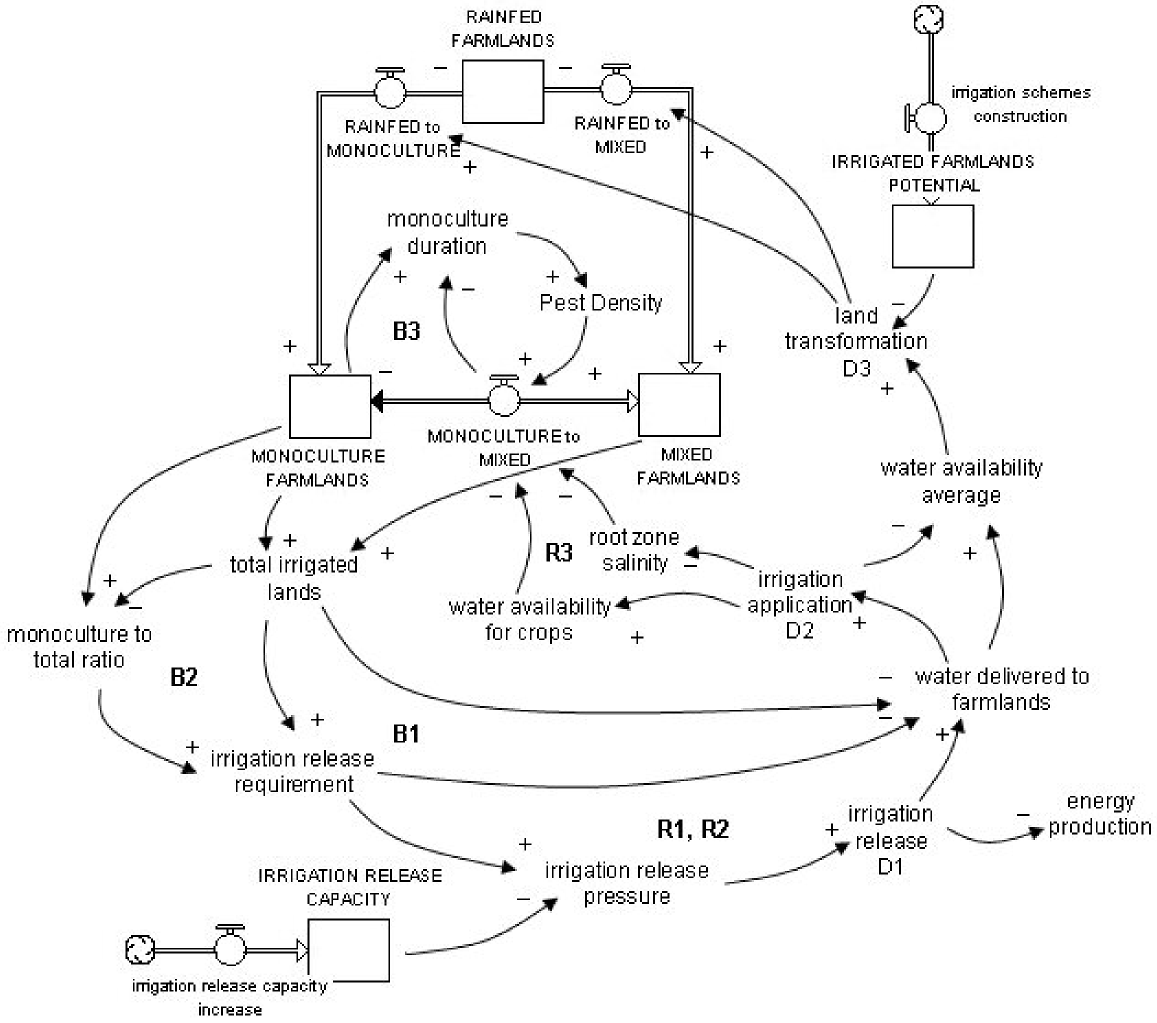

Figure 10. Causal loop diagram: irrigation release, irrigation application, land transformation, and environmental factors.

This feedback view supports model behaviour analysis. Table 1 shows the final values realised by several system variables after 30 years when the model is run according to reference behaviour exogenous scenario (22000 GWh/year energy production, 1.7 Mha irrigation target). 0 is the base case where water release policy is loose (D1, release high amount of water if available), farmers are consumptive (D2, use more water when available) and the land transformation is sensitive to average water availability (D3, be strained in land transformation if there is water scarcity). Energy production and irrigated lands stagnate below target levels, a very high percentage of basin surface water yield is diverted for irrigation, average yield losses due to water scarcity is high. Monocultures are larger than mixed farmlands by 15%. Then in experiment 1, when the water release is tightened, energy production almost reaches the target since more water becomes available for hydropower production, but irrigated lands stagnate at a very low level because average water availability is low and land transformation is slow. Again, monocultures are larger than mixed farmlands by 12% indicating a negligible shift towards mixed due to reduced water availability for crops. In experiment 2, when farmers' water consumption attitude is assumed conservative, average water availability increase and irrigated lands almost reach the target. Since irrigation application is conservative, average yield loss is considerably high and the increase in mixed farmlands compared to monocultures is remarkable. Since this shift creates a relative decrease in irrigation release requirement, energy production moderately increases. Last, experiment 3 shows that, if land transformation is less strained in front of water scarcity, irrigated lands increase, since irrigation release is tight and not responding to increased demand from irrigated lands, water delivered to farmlands decrease and water availability for crops remarkable decrease. This creates a relative shift form mono to mixed farmlands. Since irrigation release is not responsive to release requirement, energy production is not affected.

Table 1. Irrigation system performance at year 30.

Experiment		Energy production (GWh/year)	Irrigated lands (Mha)	Ratio irrig. release (fraction)	Av. yield loss-water scarcity (fraction)	Monoculture farmlands (Mha)	Mixed farmlands (Mha)
0	D1=loose; D2=consumptive; D3=sensitive	18500	1.44	0.4	0.13	0.77	0.67
1	D1=tight; D2=consumptive; D3=sensitive	21500	0.88	0.24	0.14	0.48	0.40
2	D1=loose; D2=conservative; D3=sensitive	19000	1.66	0.36	0.24	0.74	0.92
3	D1=loose; D2=consumptive; D3=insensitive	18500	1.69	0.41	0.18	0.84	0.84

Had the balance of monocultures and mixed farmlands been not influenced by several other economic and environmental factors, and this balance did not influence the overall performance of irrigation system, this analysis would be less interesting. But there are several factors affecting this balance. First, there are factors exogenous to the model, such as crop prices and ease of production and marketing conditions for certain crops which the model tries to capture with *farm constants* (see *farmlands* model description). Second, there are environmental factors endogenous to the model such as salinization, soil nutrient deficiency and pest abundance. If any of these factors create bias towards monoculture farmlands, irrigation release requirement increase inducing a decrease in average water availability and reducing land transformation rate. This would unfavourably affect overall system performance. Next we analyse the effect of salinization in this picture.

IV.2. Effect of Salinization on Irrigation System Performance

Salinization is a highly nonlinear process and a complete presentation of its feedback structure is not feasible in this paper. Model analysis show, at very low levels of irrigation, salinity increases with increasing application but at levels close to crop irrigation requirements, it decreases with increasing application. This decrease is due to increasing *percolation* and its *salt flushing*. Similar nonlinearity is observed for the effect of drainage, if drainage is mixed to freshwater supplies (Saysel and Barlas 2001). Referring back to Figure 10, under non extreme conditions where water delivered to farmlands is close to *farm irrigation requirements*, as irrigation application decreases *Salinity Rootzone* increases. High salinity relatively favours salt tolerant cotton crop. Profitability of monocultures compared to mixed farmlands increase, net flow from monocultures to mixed farmlands decrease. Monocultures become higher than they would have been if salinity had not increased. Ratio of monocultures to total irrigated lands and irrigation release requirement increase, water delivered to farmlands decrease, irrigation application reduce, rootzone salinity increase further favouring monocultures (positive feedback – R3). Table 2 adds salinization into the picture. In experiment 4, salinization is introduced without control. In experiment 5, salinization is tried to be controlled by draining the percolating water. Comparison of these two experiments with the base case show, salinization favouring the water consumptive monocultures reduce the total irrigation commend area. This effect is in place but reduced in experiment 5 where salinization is being controlled.

Table 2. Irrigation system performance at year 30, salinization introduced.

Experiment		Energy production (GWh/year)	Irrigated lands (Mha)	Ratio irrig. release (fraction)	Av. yield loss-water scarcity (fraction)	Monoculture farmlands (Mha)	Mixed farmlands (Mha)	Salinity rootzone (mg/l)
4	D1=loose; D2=consumptive; D3=sensitive; Weak salinity control	18500	1.34	0.4	0.10	0.94	0.41	5200
5	D1=loose; D2=consumptive; D3=sensitive; Strong salinity control	18800	1.39	0.39	0.13	0.85	0.54	4000

IV. 3. Effect of Nutrient Deficiency and Fertilizer Application

Next macro nutrient dynamics is introduced but the effect of salinization is ignored. Experiments with farmers' fertilizer application attitudes about placement and timing of fertilizer application (*N application effect uptake*), quantity of fertilizer application (*N deficiency effect fertilizer uptake*) and tillage practice (*tillage effect oxidation*) show that such attitudes have no systemic effect on irrigation system performance and land use. The obvious effect of consumptive fertilization attitudes is increased nitrogen leaching meaning increased pollution. But since the effect of this pollution is external to the farmers and the costs incurred by higher fertilizer consumption are negligible and symmetric between monocultures and mixed farmlands, land use and irrigation release requirements are not altered.

IV. 4. Effect of Pests and Pesticide Application

Pest dynamics represented by the model is a complex process which considers the effects of pest control threshold and Pest Density on farmers' pesticide application decision, pesticides effect on pest eradication and pest resistance building and effect of monoculture durations on pest abundance. Increasing pests and pest control requirements incur additional cost for monocultures. Even if the cost of pollution created by the pesticides can somehow be externalized by the farmers, the cost of pest control is high and unlike increasing fertilization needs, it affects the balance of farmlands in favour of mixed farmlands. Referring back to Figure 10, this process is depicted by pest density and its effect on the land flow between monocultures and mixed farmlands. As the size of monocultures relative to the land flow from monocultures to mixed farmlands gets higher, this indicates longer monoculture durations. Longer monoculture durations induce an increasing effect on pest density on monocultures. As pest density gets higher, costs associated with pest control and crop losses increase and discourage monoculture farming in favour of mixed farmlands (negative feedback, - B3). Although analyzed factors such as pest control threshold, farmers' response to increasing pest abundance, pesticide effect on pest resistance building, pest resistance building times and pesticide effect on pest eradication yield different pest densities and pesticide application rates, these processes have a relatively symmetric effect on alternative farmlands and do not have a significant influence on land flows. Feedback process depicted in Figure 10 illustrates the fundamental effect on land flows and irrigation system performance. This view supports understanding of the values realized in the experiments 6 and 7 where the pest dynamics is introduced but soil nutrients are ignored (Table 3).

Experiment 6 assumes weak effect of monoculture duration on pest density. Values realized at year 30 shows, farm system shifts towards mixed farming, irrigated lands relatively increase. In experiment 7, when this effect is assumed strong, the shift is severe, irrigated lands increase but more pesticide is being applied on the average, indicating worse conditions for the agricultural environment.

Table 3. Irrigation system performance at year 30, pests introduced.

Experiment		Energy production (GWh/year)	Irrigated lands (Mha)	Ratio irrig. release (fraction)	Av. yield loss-water scarcity (fraction)	Monoculture farmlands (Mha)	Mixed farmlands (Mha)	Pesticide appl. av. (kg/ha)
6	D1=loose; D2=consumptive; D3=sensitive; Weak mono. dur. eff.	18500	1.52	0.4	0.16	0.63	0.89	3,94
7	D1=loose; D2=consumptive; D3=sensitive; Weak mono. dur. eff	18500	1.62	0.4	0.19	0.45	1.17	4.05

IV. 5. Effect of Land Use on Agricultural Environment

As the effects of salinization and pest accumulation on land use and irrigation system performance are analyzed, effects of several other influences on land use on agricultural environment can also be examined. Model hypothesis about the rate of change between monocultures and mixed farmlands includes their relative profitability and exogenous factors representing the ease of adoption of cropping methods (see respective model description section). Therefore, in addition to the analyzed environmental factors, one can assume more favouring conditions for monocultures because of crop prices offered in the market and/or other institutional reasons supporting monocultures. Figure 11 is a dynamic analysis where whole model structure is simulated under price conditions favouring monocultures. Under these conditions, monocultures bearing the increasing cost of pest control flourish and suppress mixed farmlands. Compared to reference behaviour (Figure 9), pesticide application rates significantly increase until the cost becomes intolerable and an escape form monocultures start around year 20. Then the monoculture durations decrease, average pest abundance and pesticide application rates also. In time, the sharp increase in monoculture farmlands is balanced by increased costs. The ultimate effect in year 30 compared to the reference behaviour (Figure 9) is a bias towards monocultures, reduction in irrigated lands, relative increase in average rootzone salinity and a significant increase in average pesticide application rates.

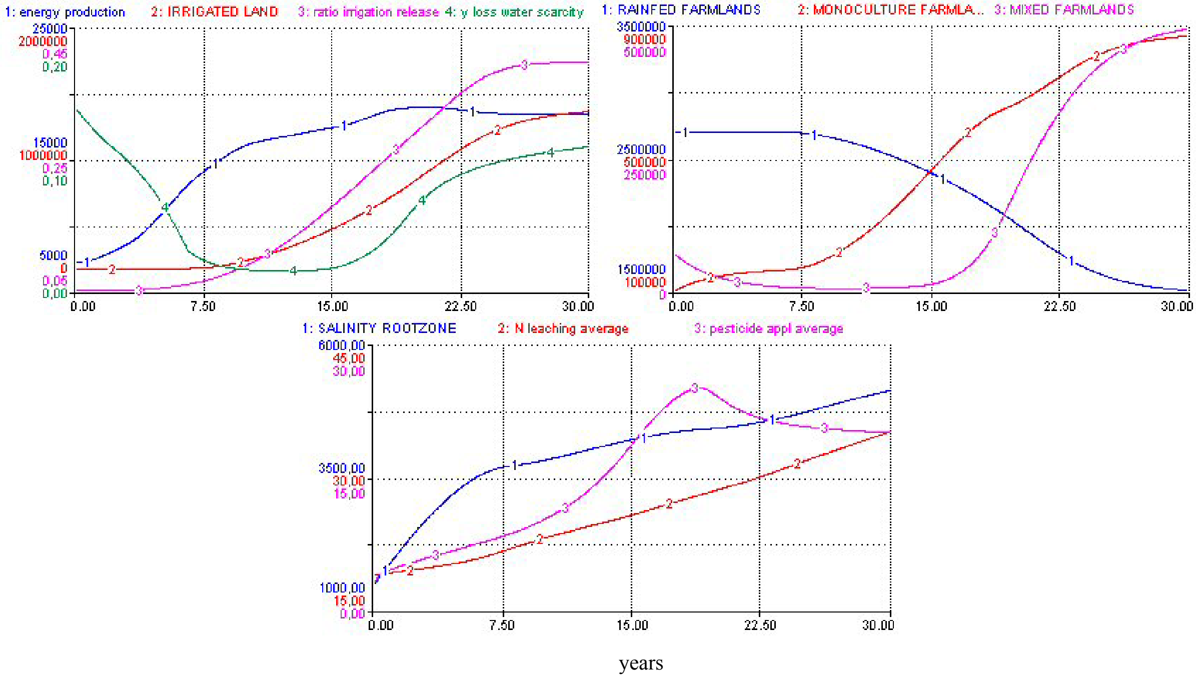

Figure 11. Scenario: price conditions favouring monocultures.

IV. 5. Sensitivity of Population and Urban Models

Is the urban development sensitive to agricultural development as alleged by proponents of big dams and large scale irrigation development schemes? To analyze this, we compare the reference behaviour with a scenario which assumes construction of hydropower and irrigation structures are altogether cancelled. In Figure 12, the left and right hand side time graphs are the reference behaviour and the scenario respectively. This analysis shows, under agricultural development, rural population decreases with migration but this tendency is reversed by the increase in agricultural jobs in the middle term. Under zero construction, rural population continue fleeing and stagnate at a lower level. The difference between the two equilibrium values is 100,000. In both cases there is a strong migration to cities. In reference behaviour food availability declines because less food staples are produced as rainfed lands are transformed; in the zero construction scenario, food availability relatively increase because rural population decrease. In reference behaviour urban job availability relatively increases and stagnates; in zero construction it declines. Year 30 values are 0.58 and 0.53 respectively. Though the dynamics are different, the dimensions achieved in the reference behaviour are far from being impressive. In non extreme scenario analysis, for example when the constructions are not totally cancelled but delayed, these differences are even more negligible. The insights of this analysis are the same when the model is tested with higher business structure growth rates and with reinforcing influence between agro business structures and other business structures. This is essentially because of the feedback view of the population and urban development models discussed in the respective model description chapters. This observation is against the alleged benefits of big dams and large scale irrigation schemes (GAP-RDA 1990; Altinbilek 2002) and supports the view in (Goldsmith and Hilyard 1984).

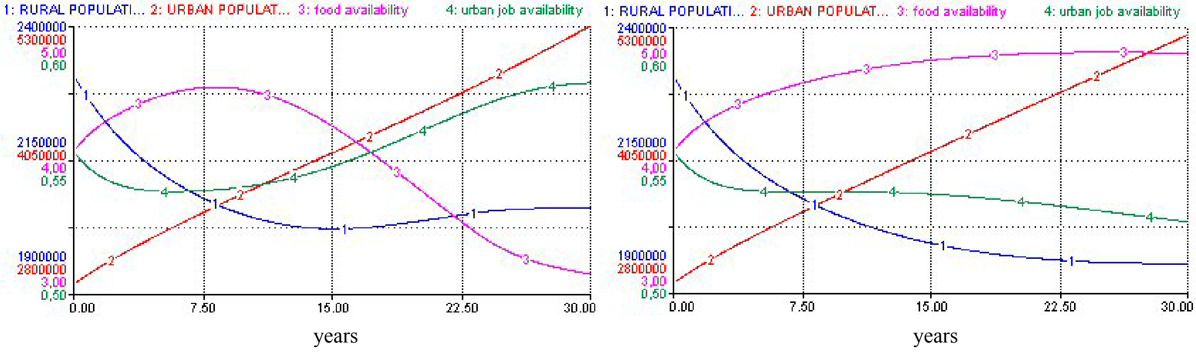

Figure 12. Urban development sensitivity to agricultural development.

V. DISCUSSION: THE USE OF MODELLING

Presented model represents the problems of irrigation systems performance and agricultural environment at a long term, regional perspective. Hypotheses on centralized water release decision and on farmers' crop selection, water consumption and agro-chemical application decisions create a dynamic complex system affecting energy production levels, irrigation command area, water availability, crop selections, agricultural environment and production in the long term. The consequences of central decisions and farmer attitudes are not trivial and the model structure and behaviour analysis is useful for improving learning, understanding and management of these problems.

Model structure and behaviour analysis shows that, irrigation development systems are prone to problems of shortfall in energy, irrigation and agricultural production targets and deteriorating environmental quality. Indeed, non of these findings are new, all established through case studies on various agricultural environments (Goldsmith and Hilyard 1984; Mannion 1995; WCD 2000). But the model structure reveals the systemic nature of these problems and the limitations of piecemeal policies to overcome the underperformance generic to large scale irrigation in many mid latitude semi arid agricultural systems. For instance, releasing large quantities of water to increase total irrigation command area can encourage increased water consumption on individual farmlands, can create a bias towards more water consumptive crops and irrigation practices rather than benefiting the whole irrigation system. Water conservation on individual farmlands or deficit irrigation can benefit the whole system by increasing the water available for other farmlands but by increasing salt accumulation in the long term can create a dead lock towards salt tolerant crops. Rapid land transformation can increase the total irrigation command area but may elevate the problems of insecure water supply in the long term, reducing the yields and frequency of crop failures. Efficient salinity control does not only benefit the individual farmlands by increasing the crop yields but can have an overall positive influence on the irrigation system since it increases the viability of salt vulnerable crops against salt tolerant ones. Successful low cost pest management policies can have an unanticipated or "side effect" to increase the attractiveness of most water demanding crops and to raise the overall water demand of the agricultural system.

Model structure and behaviour analysis also challenges the view of big damming and agricultural development as a step to industrial development and increased welfare. Model represents industrial development endogenous to agricultural development. Agro business flourishes to process the increased and diversified agricultural products and to satisfy the increasing agricultural production input demands. It also conditions growth in other business structures by creating demand for their products. As an immediate consequence unemployment rates are expected to decrease. However decreasing unemployment rates stagnate at undesired levels, increased agricultural labour requirement is not sufficient to keep the rural population, they migrate to cities to provide labour for the new industry. When business growth declines with stagnating agricultural development, additional industrial jobs are occupied by the urban residents now much bigger than what it was when the agricultural development has started.

Model can also be used to search for improved integrated policies as in (Saysel, Barlas et al. 2002). More important, model hypothesis and their dynamic consequences can further be challenged by several other case studies and by expert groups. Important function of the presented model is to provide a platform for learning about complex problems of irrigation development and agricultural environment among students, professionals and managers in the field. This generic view of irrigation development can be custom tailored for specific case studies or can be disaggregated for the analysis of more specific problems of water distribution and agricultural environment in irrigation systems. Modelling for learning among students, managers and policy makers is a is a strong view on the use and benefits of models and modelling since (Morecroft and Sterman 1994). The model and modelling approach presented in this paper may provide the foundations to initiate group learning practices in relevant organizations.

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