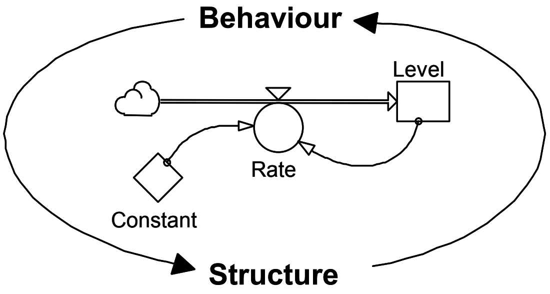
WORKING PAPERS IN SYSTEM DYNAMICS

WPSD 3/04 **ISSN 1503-4860**

MODEL SIMPLIFICATION AND VALIDATION: ILLUSTRATION WITH INDIRECT STRUCTURE VALIDITY TESTS

by

Ali Kerem Saysel and Yaman Barlas



The System Dynamics Group

Department of Information Science
University of Bergen, Norway
Postbox 7800, N-5020 Bergen, Norway

ABSTRACT

Simplification of a large system dynamics model and validation of the simplified version is illustrated. The original model represents agricultural and environmental problems of irrigation development in Southeast Turkey and consists of 62 stock variables. Its simplified version with a narrow model boundary and higher level of aggregation is a general representation of its selected dynamics and consists of 11 stock variables only. Analysis of reference behaviours, indirect structure validity tests and scenario runs reveal simplified model as a valid and useful version of the original. Simplification helps distilling essential model structures that cause selected problems and increases the quality and understanding of models. It can also be a step towards building theory-like structures and general representation of case specific problems in various application domains.

Keywords: simplification, validation, model understanding, large models, generic/general models

1. INTRODUCTION

Model simplification is a semiformal approach to distil essential structures of a large-scale model so as to create its fundamental dynamics and is a powerful method to increase model understanding. (Eberlein 1989) presents a formal theory of model simplification as a means of increasing model understanding, which identifies important feedback loops in linearized models with respect to selected dynamic behaviour. Weak feedbacks in generating this behaviour and the stock variables embedded in these loops are eliminated. The original model is collapsed to a substructure that can create the intended dynamic behaviour. Since this method is restricted to linear models, its applicability in system dynamics is limited. If supported by flexible computer implementation, such formal approach can be an invaluable support in model simplification. But simplification typically involves aggregation of stock-flow processes and parameters and requires informal reasoning beyond formal method. Once the objective of simplification is broadened as a move from case specific to generally applicable model structures, questions regarding the model boundary, level of aggregation, validity, relevance of the simplified structure to the general literature and empirical studies have to be considered.

Beyond increasing the quality and understanding of the existing models, the commitment of the system dynamics field to the idea of creating integrative theories of seemingly separate, case specific management problems motivates simplification practice. For instance, Jay Forrester’s customer-producer-employment model in Industrial Dynamics (Forrester 1961), and the model of market growth (Forrester 1968) are cited by (Lane and Smart 1995) as general models which were distilled from real world case studies and data. Through simplification, a case specific, large and parameterized model of a dynamic problem can be reduced to a generic representation of the same problem, suitable for transferring knowledge in the same domain and useful for disseminating the essential structures responsible for the problematic behaviour and mismanagement. But examining the published work, it is not evident that simplification is widely practiced in system dynamics methodology.

According to (Barlas 1998), in order to avoid criticisms regarding their models being unrealistic, modellers are tempted to built larger and more detailed models which often makes the situation even worse since the final product is large, complicated but still unrealistic. A systematic use of mental models and dynamic insights through an extensive session of model simplification can help the way out of this dilemma. Towards a completion of a study the analyst acquires a dynamic understanding of the problem that she/he did not have in earlier phases. (Barlas 1998) therefore suggests that there must be an additional final step in system dynamics modelling, namely model simplification, which completes the study cycle with a much simpler fundamental version of the working model.

In this paper we illustrate the simplification process of a large model built for long term environmental analysis of an irrigation project in Southeast Turkey (Saysel 1999) and the validation of its simplified version. Our purpose is to increase the quality and understanding of the model by eliminating its unimportant substructures and ineffective feedbacks in creating its behaviour of interest. Another objective is to move from this case specific representation of the problems of irrigation development to a general representation applicable to similar problems in semiarid mid-latitude agricultural systems. Both the original study and the simplification are done by the authors themselves and the problem framework of the original model and the dynamic insights learned from original model analysis are utilised during the simplification process. Therefore, this simplification exercise can be seen as the final step of a study cycle as suggested by (Barlas 1998). Based on selected dynamics of the original model, we created a simplified model with a narrower boundary and an aggregated view of parameters and stock flow processes (Saysel 2004). The simplification process is experimental and iterative, based on extensive sensitivity analysis with the original model. Model sectors representing various problem components, several hypotheses on decision formulations and parameters in weak feedback with respect to the selected dynamics are eliminated.

In the following sections, the original and simplified model structures are introduced. Simplification process and then the simple model structure are described. The reference behaviours, validation tests and policy runs of the original and simplified model are compared. The use of simplification as a step in system dynamics method and the advantages and disadvantages of large and simplified models are discussed.

2. THE ORIGINAL VERSUS SIMPLIFIED MODEL OVERVIEWS

The original model GAPSIM (Saysel 1999) has a large and detailed structure consisting of 14 model sectors with 62 stock and 120 flow variables in total. Model sectors consist of farmlands (*rainfed farmlands*, *irrigated farmlands* and *wineyard-garden*), a model sector representing the development of land and water resources (*land-water development*), other land resources (*rangelands* and *forests*), environmental indicators (*irrigation-salinization*, *soil nutrients*, *pests*, *erosion*), and *population*, *urbanization market* and *government*.[1] Figure 1 is an overview of the model with material and information flows between its components. Boxes stand for the model sectors while the bold arrows between some boxes represent the direction of land flows.

---

[1] Mathematically speaking the order of the model should be higher than sixty two since the environmental components are represented with array structures corresponding to each farmland, rangeland and/or forest land components. However since all these representations are structurally identical, we count them as a single stock variable. Similarly, the array structures for the environmental components are retained in the simplified version, but this time, array dimensions are decreased since farmlands are aggregated in three categories rather than eight and since rangelands and forests are dismissed.

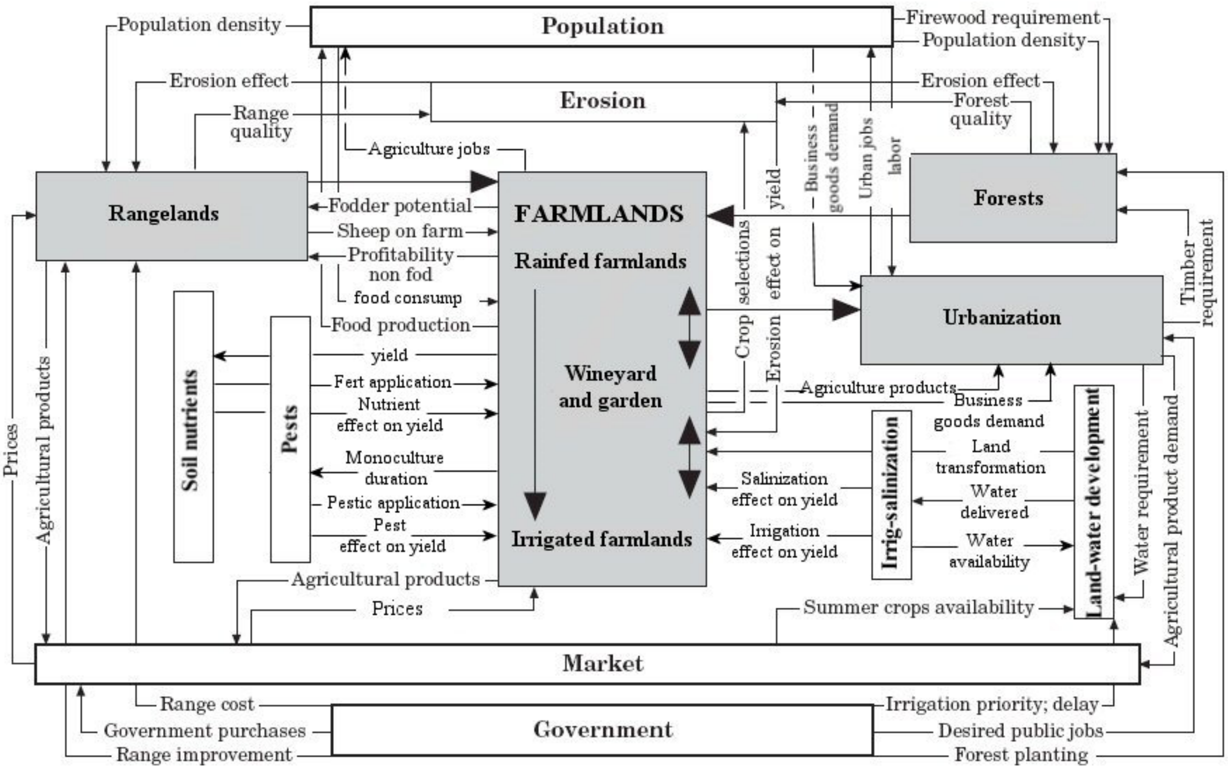


FIGURE 1. The overview of the full GAPSIM model.

The simplified model GAPSIMPLE (Saysel 2004) is a reduced version of the original one based on a selected aggregated reference behaviour of the original and a specific policy analysis focus. The aggregation process, selection of reference behaviour and the specific policy focus are discussed in the next chapter. GAPSIMPLE consists of five model sectors with 11 stock and 22 flow variables in total, i.e. it is smaller than one fifth of the original model in number of stock variables. The model sectors aggregated and retained in GAPSIMPLE are *farmlands*, *land-water development*, *irrigation-salinization*, *soil nutrients*, and *pests* (Figure 2). A larger version of GAPSIMPLE created during the simplification comprises *population* and minimized version of *urbanization* sectors and consists of seven model sectors with 15 stock and 31 flow variables. If the selection of reference behaviour and relevant model analysis is to be extended to include population variables, rural food availability and urban employment rates, this larger version of GAPSIMPLE can be useful.

However, since the existence of these model components *population* and *urbanization* do not fundamentally affect the dynamics of variables in GAPSIMPLE reference behaviour, we safely leave them out from analysis.

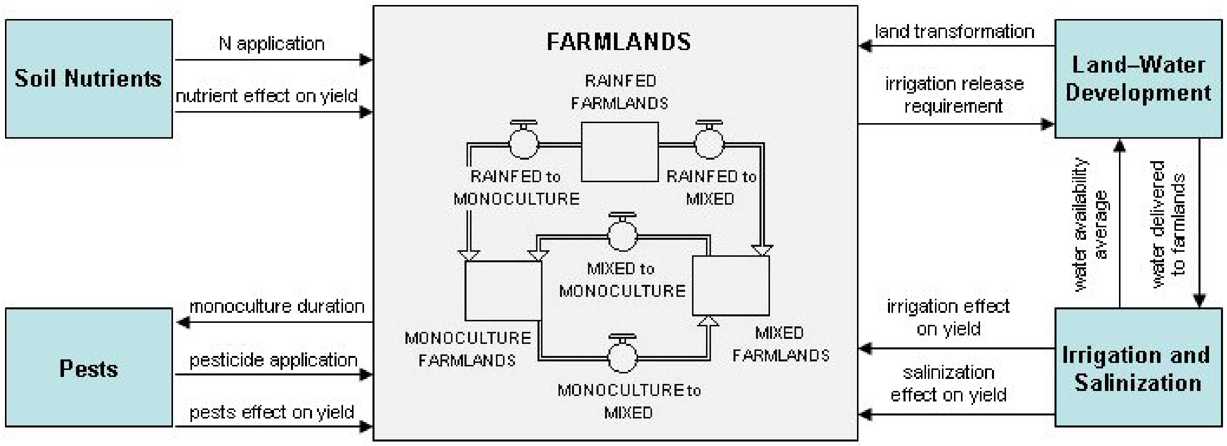


Figure 2. Overview of GAPSIMPLE.

3. THE SIMPLIFICATION PROCESS

Simplification starts with identifying a reference behaviour describing the development of a dynamic problem to be represented and analysed with the simplified model. This selection is not arbitrary but depends on the dynamic insights learned through original model building and by model analysis. Earlier analysis of GAPSIM showed, an uneven development in irrigated farmlands, a bias towards high water demanding cotton monocultures can create water scarcity at regional level and interfere with the development of irrigation into new acreages. High agricultural water demand stimulates high irrigation release and hampers hydropower production. Beyond crop market prices, agricultural inputs and environmental factors such as pest accumulation and rootzone salinization affect farm profits and therefore crop selections (Saysel, Barlas et al. 2002). The same analysis revealed, a tight irrigation release policy securing water for in-stream flow and hydropower production; encouraging the transformation from rainfed to irrigated farming within the total command area of irrigation schemes; and favouring mixed production systems against monocultures can improve the overall performance of the system (Saysel, Barlas et al. 2002). The simplification exercise presented in this paper draws on these insights and conclusions. The reference behaviour selected for this purpose is organized with four separate time graphs representing the development of *water resources*, *land use*, *agricultural environment* and *agricultural production* respectively (Figure 4). Since many variables have aggregated representation in GAPSIMPLE, the reference behaviour of GAPSIM comparable with its simplified version is designed by aggregating the original variables. Some of these aggregations are explained below. The reference behaviour is further described in the relevant chapter comparing the GAPSIM and GAPSIMPLE behaviours. However, it is important to note that this reference behaviour is one of many options one may choose as the starting point of a simplification study. In fact, arguably, starting with different reference behaviours and following different simplification paths one may create quite different simplified versions of an original model. In fact, this can be a further synthetic reality experiment to investigate the problem dependent characteristic of modelling and validation.

Once the reference behaviour and the purpose of the simplified model are identified, the simplification process is experimental and iterative. Ideally, every modification on the original model should be followed by comparing the reference behaviours, validation tests and policy runs of the original and simplified models. This demands substantial time and effort but ensures the quality of the simplified model.

In the presented simplification exercise, first, the model sectors in weak feedback with the selected reference behaviour are eliminated. With this criteria, the original model sectors *forests*, *erosion*, *rangelands*, wineyard-garden, *government*, *market*, *urbanization* and *population* are successively removed. Elimination of each sector considerably reduced the original model size. However, such eliminations are not trivial since these sectors are integrated to the others with formulations. Each elimination calls for reformulations of equations and aggregations of several variables in the retained sectors. For example, when the *rangelands* is eliminated, the stock variables representing the livestock assets are cleared. But in the original model, livestock is the basis of fodder demand and a source of income on *farmlands*. Based on fodder demand, portion of farmlands are allocated for fodder production which takes land from other production activities. Therefore, the elimination of *rangelands* calls for a relatively aggregated representation of farmland allocation, farm production, farm input and farm profit variables. Once the livestock is eliminated from the model, fodder is eliminated from production in *farmlands*. Then, no farmland is allocated and no input is used for fodder production. Cost of fodder production and revenue from livestock products disappeared in farm profit calculations. All these modifications need to be done with care and model reference behaviours, validation runs and policy runs of the original and simplified models need to be compared after each or a sequence of amendments.

The sectors retained in GAPSIMPLE go through simplification as well. Among them, the *farmlands* is considerably simplified and it deserves particular discussion. In the original GAPSIM, the farmlands were categorized under ten stock variables, two representing rainfed farmlands, four representing irrigated farmlands and four representing rainfed and irrigated wine-garden. Rainfed farmlands were disaggregated as farmlands for winter cereals and for winter cereal–winter pulse rotation farmlands. Irrigated farmlands were disaggregated into four types: cotton monoculture, cotton-other summer crop systems, winter cereals-other summer crop systems and more complex cotton-winter cereals-other summer crops sequences. Wine-garden was categorized under rainfed and irrigated wine-gardens and each category was represented with an age cohort, young and mature wine-garden. With this disaggregated view of farmlands, the idea was to represent the farm systems in the study area Southeast Turkey as detailed as possible. In GAPSIMPLE, all farmlands are represented with three stock variables, *rainfed farmlands*, *monoculture farmlands* (irrigated cotton monocultures) and *mixed farmlands* (irrigated other mixed farm system). Wine-garden is altogether dismissed. Reduction from ten to three stock representation of farmlands favourably reduces the complications in formulations and presentations of land flows in between different farmland stocks. For instance, while it is possible to represent land flows in between three farmlands with six unidirectional flow processes, if the farmlands are represented in four stocks, the number of unidirectional flows increases to 12. Because, if the modeller wants to represent all possible land flows in between n land stocks, the number of unidirectional flows connecting these stocks would be equal to *n x (n-1)*.

It is not only the number of land stocks reduced in the simplified farmlands model. GAPSIM has a highly parameterized representation of farm products, farm inputs and farm-economic calculations. Individual farm product and farm input parameters and their corresponding prices were all statistically estimated for the base year 1990. For instance, the production on farmlands was categorized under nine product groups, winter cereals, winter pulses, cotton, summer cereals, oil crops, vegetables, fruits, milk and livestock while in GAPSIMPLE, the products are *winter crops* (aggregating winter cereals and winter pulses), *cotton* and *summer crops* (aggregating summer cereals, oil crops and vegetables). Fruits, milk and livestock are ignored. Farm inputs for GAPSIM were water, phosphate and nitrogen fertilizers, pesticides, seeds for individual crops, fuel and labour. In GAPSIMPLE, *nitrogen fertilizers* and *pesticides* are the only farm inputs.

In addition to the simplification of stock flow structure and the parameters, some hypotheses in farm economic calculations and land flow decisions are omitted. For instance, in GAPSIM, the land flows are biased towards the larger farm stock, representing the assumption that more farmers favour prevailing farm systems in a rural environment. This assumption does not exist in GAPSIMPLE. From feedback point of view, any reduction in number of stock variables, number of parameters creating a chain of calculations, or in number of hypotheses guiding the formulation of decision rules effectively eliminates numerous feedback loops which do not contribute the selected model behaviour and considerably simplifies the feedback complexity of the model structure.

It is worth mentioning that the aggregation represented in the reference behaviour (Figure 4) is not decided per se before the simplification. As already described, together with the dynamic insights learned from the original study, the simplification exercise guides what should be kept and what should be leaved out in the simplified model. This process gradually channels the analysis towards an aggregation level, a general representation feasible with a minimum structure. The simplification process stops where further simplification creates flaws in the simplified structure diagnosed by analysing reference behaviours, validation runs or by policy/scenario analysis.

In GAPSIM, representation of *land-water development*, *irrigation-salinization*, *soil nutrients* and *pests* are less detailed and less parameterized compared to the farmlands representation. Therefore, in GAPSIMPLE, they have similar aggregation levels to their counterparts in GAPSIM.

4. SIMPLIFIED MODEL

It is said, one objective of simplification is to increase the understanding of models. Given the complexity and size of GAPSIMPLE, it is still not feasible to illustrate all stock flow processes on a single diagram. But, to illustrate how the simplified model helps understand the integrity of the water development, land use and environmental processes, we provide a feedback view of GAPSIMPLE (Figure 3). Irrigation authorities' water release decision

(Decision 1), farmers' irrigation application (Decision 2) and land transformation (Decision 3) decisions are represented in feedback. In principle, a similar feedback structure can be extracted from the original model, GAPSIM. However, with the detailed and parameterised structure of GAPSIM, it is much more difficult to distil and communicate this information. Extensive sensitivity analysis on various model components during the simplification process helps identify the feedback loops contributing model behaviour. Reduced number of stock variables allows a clear illustration of the important feedback processes. Figure 3 plays important role in understanding the model behaviour and policy analysis as discussed and demonstrated in (Saysel 2004).

Figure 3 shows, total *irrigation release requirement* of the system increases 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 (Decision 1), *water delivered to farmlands* and the *average water availability* rise. This encourages *land transformation* (Decision 3) and irrigated lands (both monoculture and mixed) increase as a result. 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 apparent self reinforcing loop (positive feedback – R1, along the outside border) 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 (Decision 1 is loose), i.e. they tolerate high demand providing whatever is required, *water delivered to farmlands* increase, *average water availability* rise, this encourages *land transformation* and irrigated lands become higher than they would have been otherwise. Therefore, an effect of loose release policy (Decision 1) is fast land development, and increased irrigated lands if there is capacity available (R1 loop). A second implication of loose release policy 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 compared to the winter and summer crops, which would 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 otherwise. A consequence of this loop is increased monoculture-to-total ratio and increased 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.

If farmers' irrigation attitude is consumptive (Decision 2 is consumptive), i.e. they tend to consume more of the water they receive on their farmlands, 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.

If farmers' land transformation decision is less sensitive to average water availability (Decision 3 is insensitive), i. e. they choose to switch to irrigated farming no matter if there is low water availability, land transformation is faster; irrigated lands become higher than they would have been otherwise.

All these processes are either growth dynamics 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 loop - B1). Any increase in the relative size of monocultures is balanced by increased irrigation release requirement and decreased water delivered to individual farmlands (because water is proportioned to individual farmlands as a fraction of total irrigation release requirement), less irrigation application and conditions relatively favouring mixed farmlands (B2).

Salinization and pest accumulation also play role in this picture. Under non-extreme conditions where water delivered to farmlands is close to *farm irrigation requirements*, as irrigation application decreases, *Salinity Rootzone* increases. This is because salt flushing effect of deep percolation is less than the salt releasing effect of evapotranspirating water. Salinity dynamics is further complex depending on the salinity of intruding groundwater. This effect is not discussed in depth in this diagram. High salinity relatively favours salt tolerant cotton crop. As salinity increases profitability of monocultures compared to mixed farmlands increase, net flow from monocultures to mixed farmlands decrease. Monocultures become higher than they would have been otherwise. Ratio of monocultures to total irrigated lands and irrigation release requirement increase, water delivered to farmlands decrease, irrigation application diminishes, rootzone salinity further increase favouring monocultures (positive feedback loop – R3).

As the size of monocultures relative to the land flow from monocultures to mixed farmlands gets higher, this indicates longer monoculture regime 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 loop - B3). Although several other factors existing in the model (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 different pesticide application rates, these processes have relatively symmetric effects on alternative farmlands and do not have a significant influence on land flows. Feedback processes depicted in Figure 3 illustrate the fundamental effects on land flows and irrigation system performance.

Finally, macro nutrient dynamics and soil fertilization is analysed. Experiments with farmers' fertilizer application attitudes about placement and timing of fertilizer application, quantity of fertilizer application and tillage practice 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. Therefore soil nutrients is not represented in Figure 3 but retained in reference behaviour (Figure 4) in order to provide a complete picture of the simulated environment.

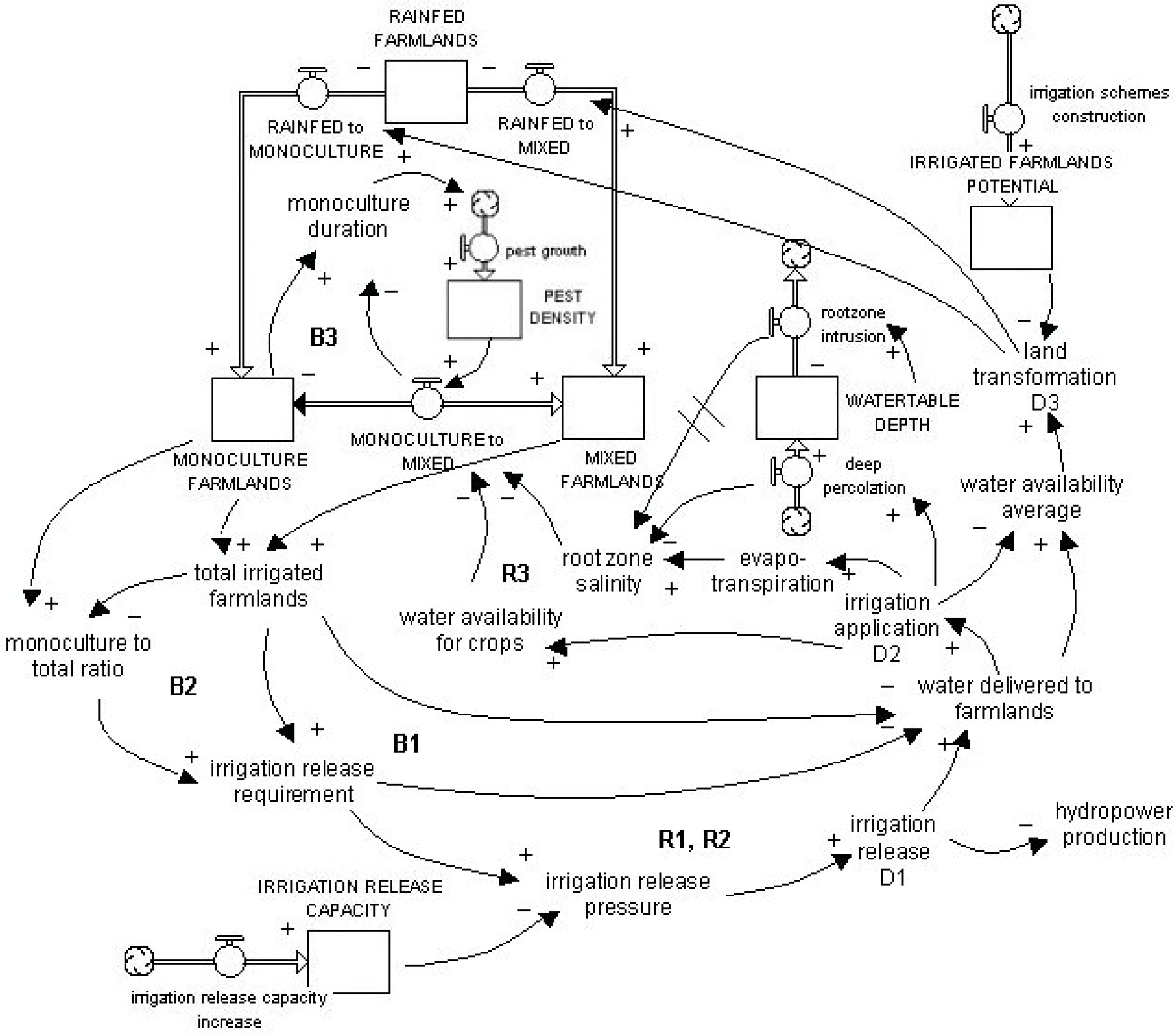


Figure 3. GAPSIMPLE causal loop diagram: irrigation release, irrigation application, land transformation, salinization and pests.

5. REFERENCE BEHAVIOURS

To illustrate that the simplified model is a valid representation of the original with respect to the dynamic problems of interest, we first discuss and compare the reference behaviours (Figure 4). This comparison is based on a visual assessment of behaviour patterns such as increasing growth, decreasing growth, growth and decline etc. but not according to numeric criteria. Given that the outcome of a system dynamics model is behaviour pattern prediction rather than point forecast and even the outcome of the original GAPSIM is highly questionable from the point of numeric accuracy compared to data, behaviour pattern match is considered as sufficient.

Reference runs are based on exogenous assumptions of hydropower and irrigation structure construction rates and the development scenario presented here is identical to the one analysed with GAPSIM in (Saysel, Barlas et al. 2002). According to this scenario, the energy production target (after irrigation release) is 22,000 Gwh/year and the irrigation target is 1,780,000 hectares.

We claim that the reference behaviours generated by the two models are similar. 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 estimations. As irrigated lands increase the *ratio of irrigation release* to total basin yield (fraction) also increases (first row of graphs, Figure 4). After the initial increase and decrease, the average *crop yield loss due to water scarcity* (fraction of potential yield) first gradually increases but never reaches alarming levels.

The major reason for the underperformance of energy and irrigation target 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 (Figure 4, second row). While *rainfed farmlands* (ha) decrease, the two irrigated fields, *monoculture farmlands* (ha) and *mixed farmlands* (ha) increase, however the ratio of water consumptive cotton monocultures among irrigated fields is considerably high.

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 the increasing chemical fertilizer consumption resulting in increased average *nitrogen leaching* (kg/ha/year). The bias towards monoculture farm activity increases the need for pest control, average *pesticide application* (kg/ha/year) first sharply increases, but then it levels off as monoculture durations decrease because farmers tend to prefer mixed farm systems as pest control on monocultures becomes more and more costly (Figure 4, third row). Agricultural production shifts from *winter crops* food grains to cash crops such as *cotton* and other *summer crops* (Figure 4, fourth row).

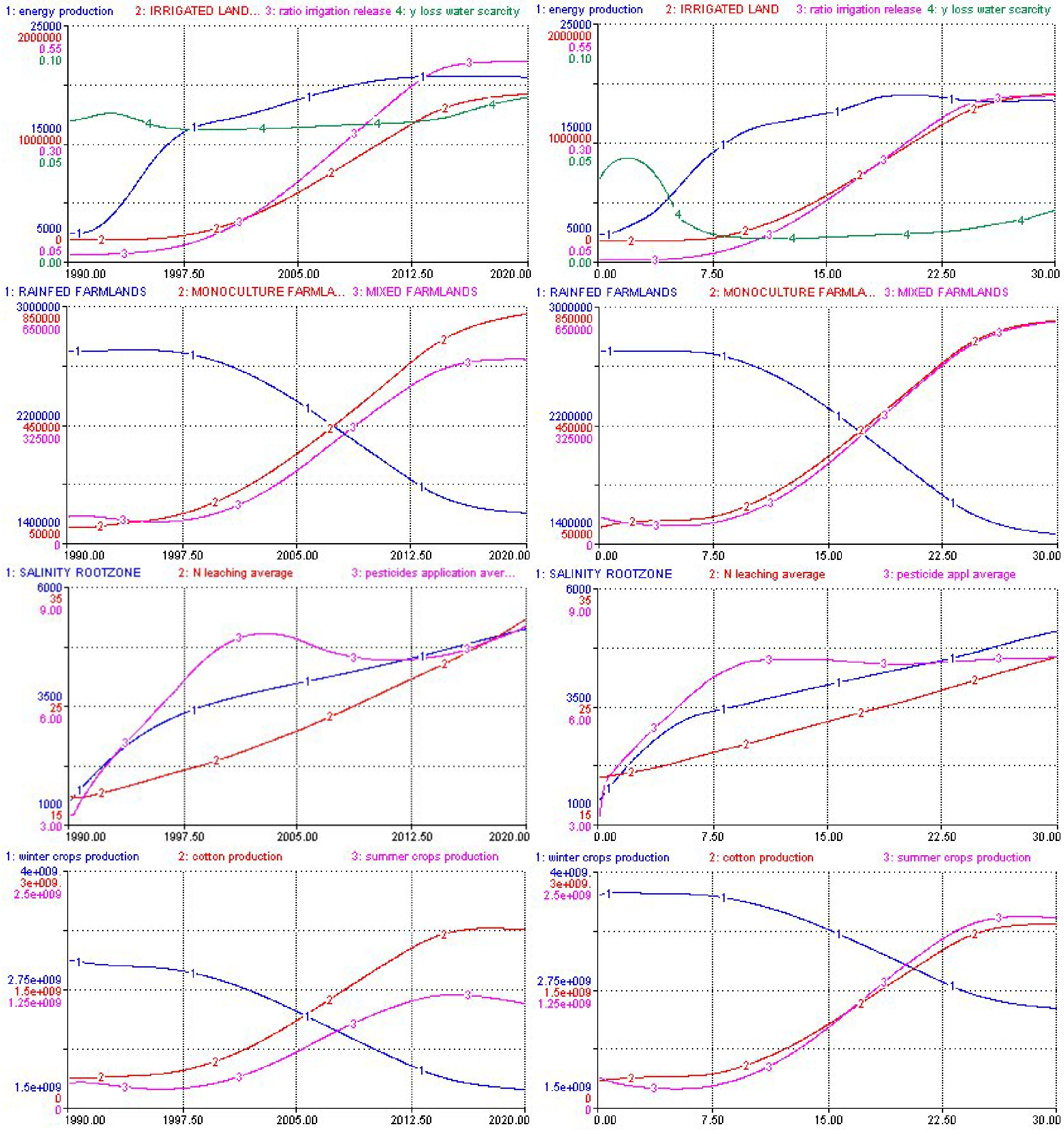


Figure 4. GAPSIM (left) and GAPSIMPLE (right) reference runs – time axis: year.

6. VALIDATION WITH INDIRECT STRUCTURE TESTS

Comparison of the reference behaviours of GAPSIM (62 stock variables) and GAPSIMPLE (11 stock variables) is a preliminary observation on the equivalence of the simplified structure to the original with respect to the selected dynamics. However, this observation itself is far from being sufficient to claim the reduced model as a valid simplified version of the original one. After all, the observed behaviour match can be spurious, i.e. the simplified model can be creating similar dynamics for the wrong reasons. To build confidence in the simplified model structure as a valid approximation of the original, we apply several indirect structure tests. Indirect structure tests involve simulation runs and can provide information about possible flaws in model structures (Barlas 1996). Among these, *extreme-condition*, *behaviour sensitivity*, *boundary adequacy* and *phase relationship* tests are particularly important for the purpose of our validation analysis (Barlas, 1996; Forrester and Senge, 1980). In this section, our approach is similar to that in (Barlas 1989), where several model structures are confronted with indirect structure tests (structure oriented behaviour tests) to the so-called "synthetic reality", a structure supposed to be a perfect representation of the reality. Given the purpose is model simplification, here we test the validity of the GAPSIMPLE with respect to GAPSIM – our synthetic reality.

Indirect structure tests can be performed for isolated model components as well as for the whole model structure. Here, we prefer illustrating the tests on whole model structures rather than the individual components since tests on whole model structures are more sophisticated and would provide stronger information about the analogy of the two structures. However for each test, only a selected set of behaviours (as opposed to all behaviour patterns) exhibiting significant modifications are demonstrated.

First, we apply an extreme condition test in which the price for cotton crop is set extremely high. Left and right hand columns in Figure 5 show this extreme condition run for GAPSIM and GAPSIMPLE respectively. Since cotton crop is valuable, profitability of cotton production is much higher than its alternatives and the farm systems shift towards cotton monocultures while mixed farmlands almost disappear. As the entire farm system shifts towards monoculture, pests prevail, pesticide application rates increase and since cotton is extremely profitable, monocultures can bear the cost of increasing pesticide use. Note the fundamental similarity of behaviour patterns in the two columns in Figure 5.

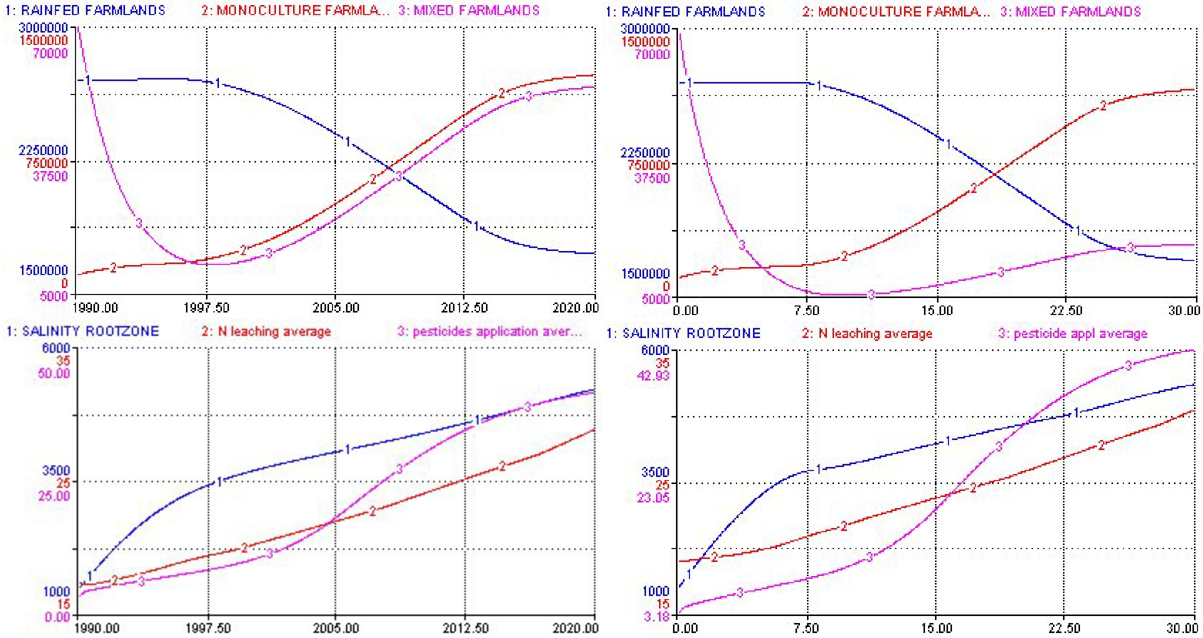


Figure 5. Extreme high *cotton crop price*. GAPSIM (left) GAPSIMPLE (right) – time axis: year.

Second extreme condition test is for extreme high summer crops price (Figure 6). This time, the agricultural system shifts towards mixed farmland which incorporate high amount of summer crops and cotton monocultures almost disappear. This favours reduction in pests and in pesticide application to control pest populations. As a side effect, the average rootzone salinity decreases since the on mixed farmlands it is relative less when compared to monocultures.

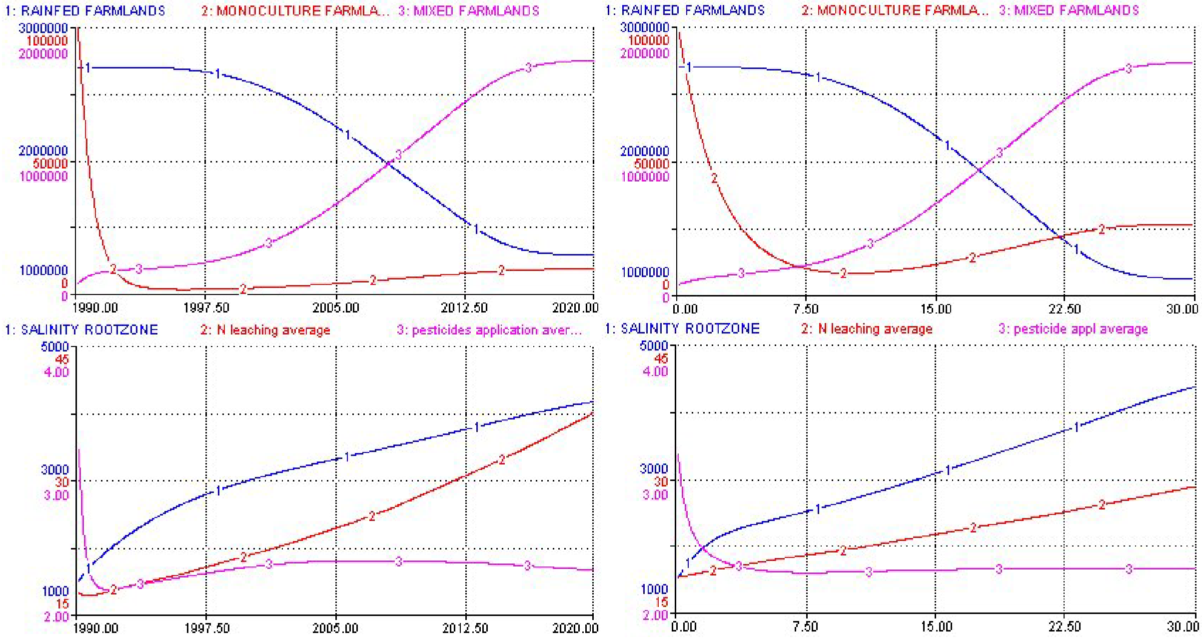


Figure 6. Extreme high *summer crops price*. GAPSIM (left) GAPSIMPLE (right) – time axis: year.

In a third extreme condition test we analyze model behaviour response to zero freshwater salinity (Figure 7). In these runs salt in the rootzone is washed by the non-saline irrigation water, rootzone salinity gradually declines and settles at a low equilibrium value. Reduced salinity favours mixed farm systems and average pesticide application declines when compared to the reference behaviours. Also note the fundamental similarity of patterns in Figure 7.

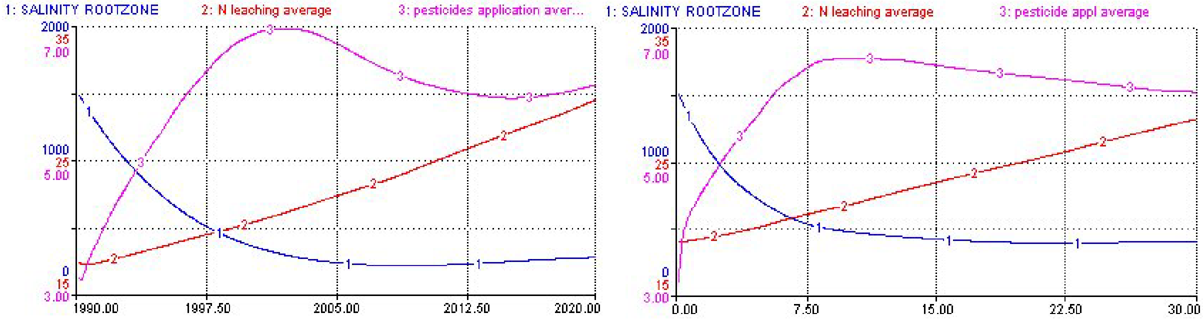


Figure 7. Extreme low *freshwater salinity*. GAPSIM (left) GAPSIMPLE (right) – time axis: year.

Fourth, with a parameter sensitivity test, we illustrate the model behaviour response to changing pest resistance building time (Figure 8). As the parameter *time to build pest resistance* increases, the increase in pest abundance and therefore the increase in pesticide application are delayed. Delayed increase of pesticide application favours the monocultures since those are the farm systems, which highly bear the increasing cost of pesticides. As a result, as pest abundance and pesticide application increase are delayed, the farm systems shift towards monocultures. Note the fundamental similarity of patterns in Figure 8.

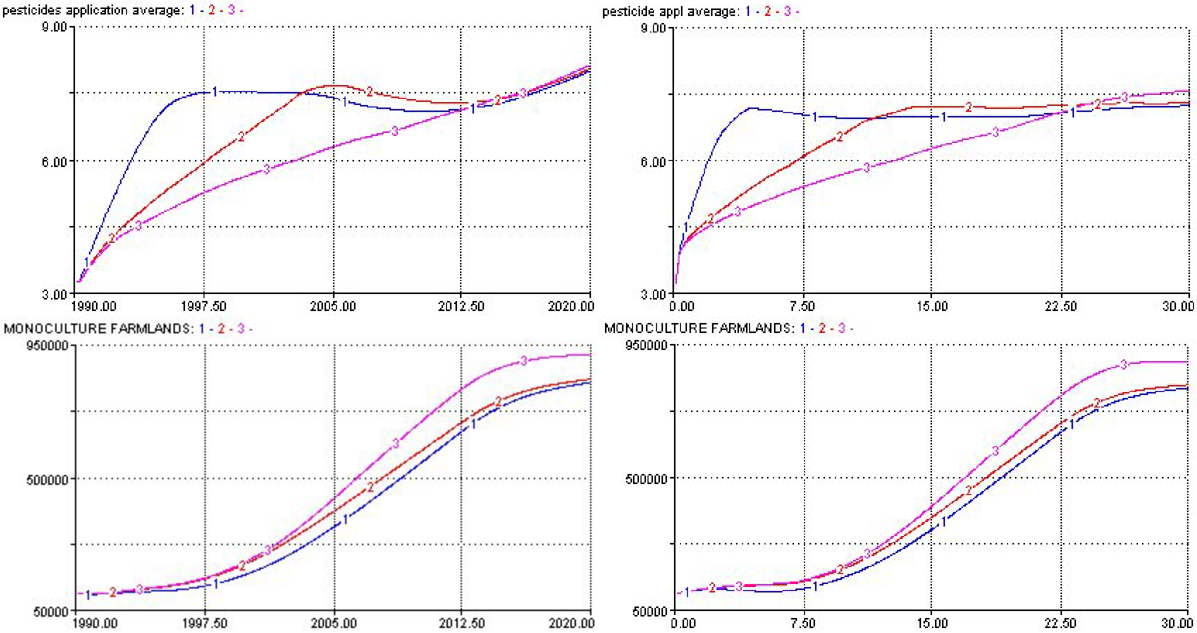


Figure 8. Behaviour sensitivity to increasing *pest resistance building time*. GAPSIM (left) GAPSIMPLE (right) – time axis: year.

The fifth test is the analysis of behaviour sensitivity to changing freshwater salt concentrations (Figure 9). As farmlands are irrigated by more saline freshwaters (200, 400 and 500 mg/l in this particular test), average rootzone salinity becomes higher. Increased salinity favours the monocultures since cotton is the most salt tolerant crop. Though this effect is less in the simplified model, it is in the right direction. Finally, as monocultures are favoured by increased rootzone salinity, average pest abundance and therefore average pesticide application rates increase.

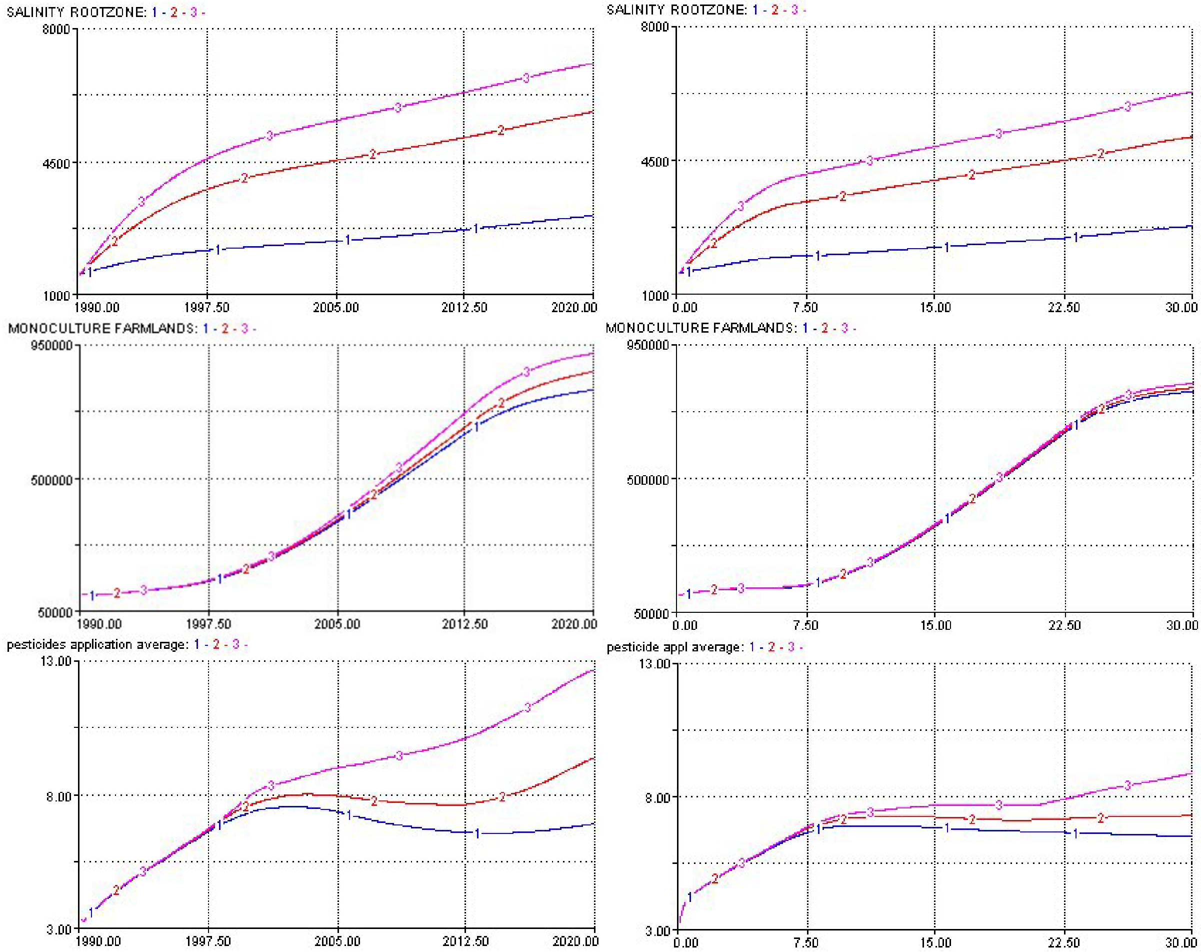


Figure 9. Behaviour sensitivity to increasing *freshwater salinity*. GAPSIM (left) GAPSIMPLE (right) – time axis: year.

It is possible to enlarge the discussion on validity in the simplification process by referring to *boundary adequacy tests*. The boundary adequacy test considers structural relationships necessary to satisfy a model's purpose; it asks whether or not model aggregation is appropriate and if a model includes all relevant structure (Forrester and Senge 1980). What the model boundary of GAPSIMPLE lacks could be relevant aspects of the reality such as other land resources (farmlands, forests, wineyards and gardens), other land degradation factors (erosion) and a dynamic price adjustment mechanism (market). A model critique can also argue against the aggregation of farmlands, farm products (cereals, pulses, summer cereals, oil crops, vegetables, fruits and livestock) and farm inputs (seeds and farm energy inputs) in the simplified model. For a study targeting the analysis of other land resources, production of individual crops or consumption of individual farm inputs these criticisms can be relevant. However, for the selected reference behaviour, the comparison of the reference runs (Figure 4) and indirect structure validity tests (Figure 5 to 9) build confidence on the boundary adequacy of the simplified model with respect to the original one.

Finally, validity of GAPSIMPLE compared to GAPSIM can be elaborated referring to the *phase relationship tests*. The idea of phase relationship test is to confront the observed phase relationships between variable pairs in the model with that observed or expected from the real system (Forrester and Senge 1980). In our case, since the original GAPSIM stands for the "synthetic reality", we compare the phase relationships observed in the behaviour of the simplified model with that of the GAPSIM. For instance, referring back to Figure 4, one can observe that in GAPSIM, the increase in monoculture farmlands and mixed farmlands are in phase and is accompanied by a decrease in rainfed farmlands. The same observation is true for GAPSIMPLE, although the farmlands have a much more aggregate view in this model. Similarly, in GAPSIM, the increase in cotton and summer crops production are in phase and is accompanied with a decrease in winter crops production. Same observation holds for GAPSIMPLE, although it has a highly aggregated representation of agricultural products distributed over various farmlands. Furthermore, essential phase relationships are preserved under extreme condition tests. For example, in Figure 6, where monoculture farmlands sharply decline because summer crops have extremely attractive price, this decline is followed by an increase in mixed farmlands and a decrease in rainfed farmlands. Same observation is true both for GAPSIM and for GAPSIMPLE.

These observations based on extreme condition, parameter sensitivity, boundary adequacy and phase relationship tests increase confidence on GAPSIMPLE as a valid simplified representation of GAPSIM. These tests do not prove GAPSIMPLE as a perfect simplified version of the original, in the sense being capable of reproducing all the behaviours of GAPSIM with numeric accuracy. Illustrations in this section are a selection of validation tests among many, which gradually help building confidence in the simplified model structure as a valid representation of the original one useful for its specific purpose.

7. POLICY/SCENARIO RUNS

How useful is GAPSIMPLE as a simplified version of GAPSIM? Formal structure validation tests partly answer this question. In order to further discuss the usefulness of GAPSIMPLE as a useful version of GAPSIM, we compare the results of policy/scenario analysis with the two models. According to the selected policy, in order to prevent the farming system shifting strongly to monocultures (consuming high amounts of water interfering with hydropower production and consuming high amounts of agro chemicals deteriorating the environment), water release policy is tightened; farmer decisions on switching from rainfed to irrigated farming is assumed to be less sensitive to water availability on the individual irrigation outlets; and more favourable conditions for mixed farming systems are assumed. This policy/scenario is described in detail in Saysel (1999) and in (Saysel, Barlas et al. 2002).

Figure 10 compares the overall behaviour of GAPSIM and GAPSIMPLE under this scenario. As water release is tightened in front of increasing water demand, water available for hydropower generation increases. Energy production stabilizes at levels more close to the target levels. Farmers not discouraged with decreasing water availability switch fast to irrigation, irrigated lands increase but water availability on individual farmlands decrease. This results in increasing yield loss but it does not reach alarming levels. Since conditions favouring mixed farming systems is assumed, monoculture farmlands do not dominate the whole farm system. This successfully reduces the pesticide application rates favouring the environmental conditions. Unfortunately, salinization and leaching nitrogen control is not successful under this scenario. Agricultural production follows parallel dynamics with land use. Again, note the behaviour pattern match between left and right columns.

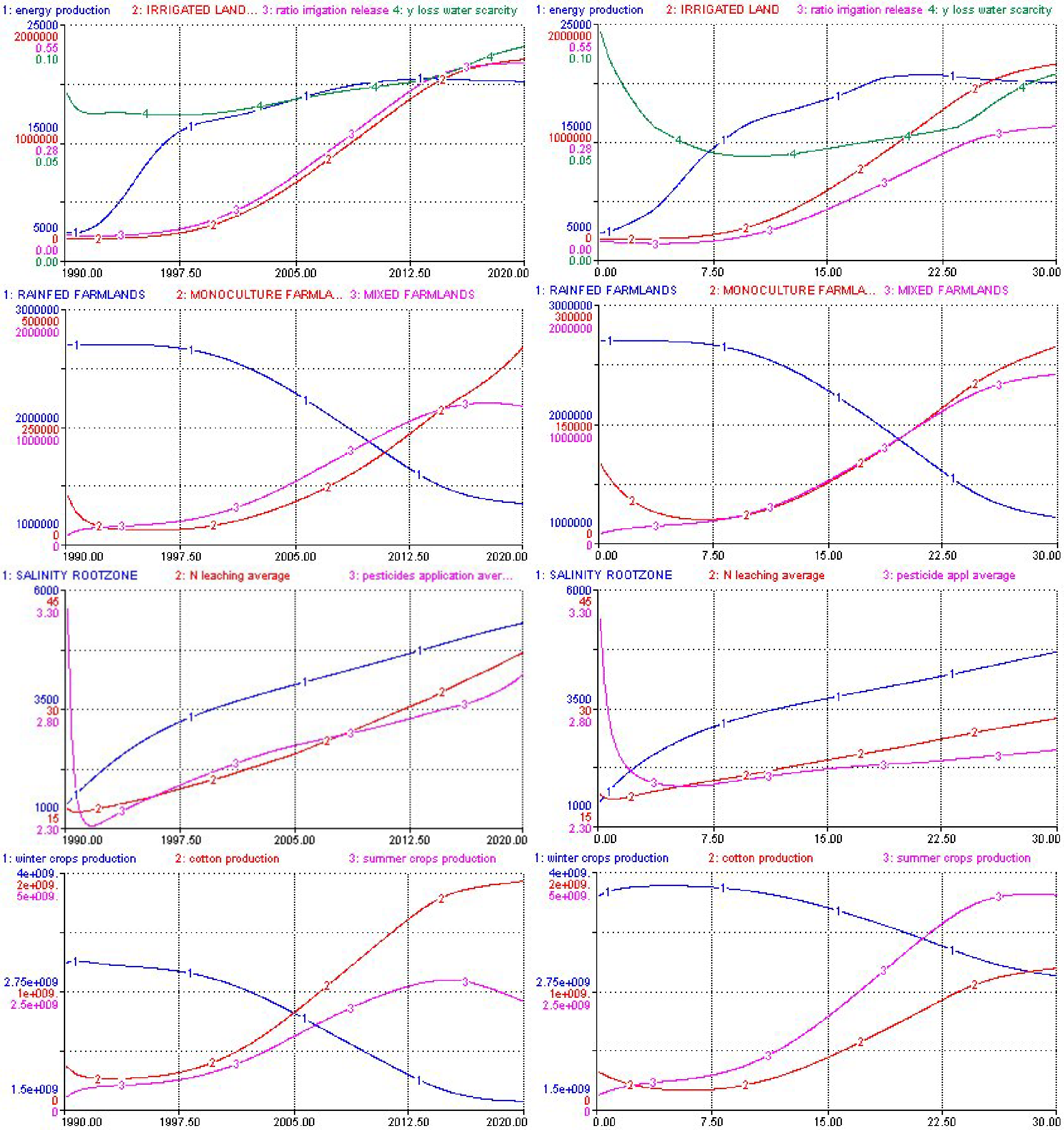


Figure 10. Scenario analysis with GAPSIM (left) and GAPSIMPLE (right) – time axis: year.

8. DISCUSSION

Simplification helps increasing the quality and understanding of existing models and has important implications for the system dynamics method in general regarding the problem identification, boundary selection, model formulation and testing phases of the analyses.

The problem oriented character of system dynamics modelling has been discussed by several authors and textbooks, see for example (Randers 1980; Richardson and Pugh 1981; Ford 1999; Sterman 2000). It is anonymously argued that a good system dynamics analysis starts with the articulation of the dynamic problem, which can be represented by the behaviours of selected variables over a definite time horizon. This time behaviour identifies the reference mode of the analysis. Model boundary is drawn by the hypothesised endogenous variables and factors affecting this time behaviour over the definite time horizon and therefore depends on the articulated problem. Formal model building and validation is perceived as a process of testing the power and validity of this hypothesis in explaining the causes of the problematic behaviour. This pedagogical view of system dynamics method helps the analysts keep focus on the problem and not fall into unnecessarily detailed, messy and less useful modelling practices.

From this perspective, there would be good and bad models, models with a clear view of stock-flow dynamics and feedback structures much closer to a theory of a dynamic problem, and models with their unclear and vague picture of stock-flow dynamics and messy feedback structures far from being an explanatory instrument of analysis. Commitment to the scientific method and experience is expected to increase the quality of models. But in system dynamics in practice, is it altogether possible to avoid unnecessary structures not contributing to the selected dynamics?

Though our starting model in this simplification exercise is not the best model committed to this scientific view of system dynamics method, in simulation models it can be inevitable to avoid structures not contributing to the creation of intended reference modes and policy analysis objectives. Referring to the vast amount of information provided by the theory and the empirics, it can be difficult for the analyst to grasp the essential knowledge, which should form the fundamentals of a good system dynamics model. In many cases, starting reference modes can be ambiguous or can be distorted by measurement errors or by several other sources of bias. By the nature of model based inquiry, analysts incorporate hypothesis in their models which may not contribute to the behaviour on their own but supposedly may have effect soon when coupled with the potential additions to the model structure. Simplification exercise as practiced here as a step after model building and validation would increase the quality of models by selecting out the most relevant structures to its purpose and contribute in its understanding. Formal methods of simplification like in Eberlein (1989) with flexible computer implementation would be invaluable support in this process.

Another objective of simplification can be to create general models (theories) from case specific ones. For many case specific researches, a disaggregated and parameterized view of the dynamic processes may be favoured against an aggregated and simplified view because of the purpose of that study and availability of disaggregate data for validation purposes. Also, the clients may be more interested to see, or may feel more confident when the model structure involves and simulates the parameters common in many field studies. On the other hand, supported and validated against several case specific models, simplified structures distilled form these models can serve as generally applicable models transferring knowledge and insights within an application domain. These models can contribute to the understanding of original models while the original models support the validity of simplified structures. Case specific models and their simplified, generic/general versions can support each other in practice.

References

Barlas, Y. (1989). Tests of model behavior that can detect structural flaws: demonstrations with simulation experiments. Computer Based Management of Complex Systems. P. M. Milling and E. O. K. Zahn. Germany, Springer-Verlag**:** 246-254.

Barlas, Y. (1996). "Formal aspects of model validity and validation in system dynamics." System Dynamics Review **12**(3): 183-210.

Barlas, Y. (1998). President's adress. 16th International System Dynamics Conference, Quebec City, Canada.

Eberlein, R. L. (1989). "Simplification and Understanding of Models." System Dynamics Review **5**(1): 51-68.

Ford, A. (1999). Modeling the Environment: An Introduction to System Dynamics Modeling of Environmental Systems. Washington, D. C., USA, Island Press.

Forrester, J. W. (1961). Industrial Dynamics. Cambridge: Massachusetts, MIT Press.

Forrester, J. W. (1968). "Market Growth as Influenced by Capital Investment." Industrial Management Review **9**(2): 83-105.

Forrester, J. W. and P. Senge (1980). Tests for building confidence in system dynamics models. TIMS Studies in Management Sciences. A. Legasto, J. W. Forrester and J. Lyneis. New York**:** 209-228.

Lane, D. C. and C. Smart (1995). "Reinterpreting 'generic structure': evolution, application and limitations of a concept." System Dynamics Review **12**(2): 87-120.

Randers, J. (1980). Guidelines for Model Concenptualization. Elements of the System Dynamics Method. J. Randers. Cambridge, Masschussets, Productivity Press**:** 320.

Richardson, G. P. and A. L. Pugh (1981). Introduction to System Dynamics Modeling with Dynamo. Cambridge, Massachussets, Prductivity Press.

Saysel, A. K. (1999). A Dynamic Simulation Model for Long Term Comprehensive Environmental Analysis of GAP. Institute of Environmental Sciences. Istanbul, Turkey, Bogazici University**:** 258.

Saysel, A. K. (2004). Dynamic Integrated Environmental Assessment of Large Scale Surface Irrigation Systems. Working Papers in System Dynamics, 2/04, ISSN 1503-4860. University of Bergen, PB 7800, N-5020, Norway.

Saysel, A. K., Y. Barlas, et al. (2002). "Environmental sustainability in an agricultural development project: a system dynamics approach." Journal of Environmental Management **64**: 247-260.

Sterman, J. D. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World, McGraw-Hill.