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Future water supply and demand assessment in peri-urban catchments using system dynamics approach

Walton, B. [1], B. Nawarathna[1,2], B.A. George[1], and H.M. Malano[1,2]

[1] *Department of Civil and Environmental Engineering, University of Melbourne, Australia*
[2] *Cooperative Research Center for Irrigation Futures*
Email: bnaw@unimelb.edu.au

Abstract: Having effective modeling tools at the disposal of catchment managers and planners are essential to developing more effective future water management strategies. The actual projections of the demand and supply are often very dependent and interrelated with many variables, including each other for most catchments. The traditional approach used by water managers, whereby the demand based on population increase trend and water availability (supply) forecasts are calculated separately, is limited in its use due to this restriction. This is most noticed through the lack of consideration of the dynamic interrelationships that can occur between the supply and demand sides of water. This is where System Dynamic modelling can be used as a novel technique that can consider all the interdependencies to help accurately assess a catchment's future water availability and use.

This report looked at creating a generic model of a catchment with competing demands and supply considerations that also modelled the important interrelated variables using the System Dynamic modelling technique (using the program VENSIM). To test the model, the peri-urban South Creek catchment of Western Sydney was chosen as a case study to run future water scenarios. Future water supply and demand scenarios were run in the model to understand the likely future water security of the catchment, as well as possible solutions to the water security issues that may arise

The South Creek catchment is an excellent case study to use for this example. With the predicted landuse or demand changes, as well as the probability of climate change, we will see dynamic changes caused by these two variables influencing the future water security of the catchment.

The consensus of the models outputs showed that the South creek catchment was likely to not severely stress its surface water resources in the future (25 years) as urban and irrigational demand increased. It also showed that if the potable water resource coming into the catchment was limited in the future, that the catchment would likely be able to draw on its own resources to cover any shortage without a detrimental effect on the catchment's water resources. This also implied that irrigational activities relying on non-potable surface water in the region could also likely increase their water use if necessary.

The model created did achieve the objectives set out for it, but future further development of it could ensure a more accurate output from the model to conclude upon. But regardless, at its current stage, it should be able to be used to give a reasonable representation of the future water security for most catchments big and small.

Keywords: *System Dynamic, Peri-Urban Catchment, South Creek, Urbanization, Climate Change*

1. INTRODUCTION

The development of accurate and informative integrated water models that help water managers better understand the issues within their catchment at present and in the future is a key issue; if done correctly it can lead to the development of timely projects for securing future water resources. Currently, as can be seen in the regions of Australia suffering the effects of a prolonged drought and possible climate shift, this is an increasingly crucial issue. With water scarcity coming to the forefront of public debate, and the likelihood of an increase in the pressure on water security due to forecast increasing demands and decreasing supplies, it is important for water managers to model accurately the impact of the long term scenarios that are likely to be faced in the future. The older and simpler models that consider the demand (population) and supply trends as separate independent variables are no longer a suitable method due to the reality of the dynamic interdependencies between many of the variables (Nandalal et. al. 2006, Kashimbiri et. al. 2005). This is where the system dynamic (SD) modeling tool can be used to model the dynamic interdependencies of the variables within a water balance model for a catchment with competing demands for the resource.

In regards to the scope of this project, the SD model developed in this work will detail the important water demand and supply scenarios of the South Creek catchment of Western Sydney (~620 sq km), and the entwined positive and negative dynamic feedbacks on these two variables (using the SD software VENSIM). But it must be noted here, that the SD model is intended to be be moderately generic, and so that it can be applicable to catchments with different scales and landuse characteristics. It must also be said that for a water manager to consider the scenarios facing the irrigation industry that he must also more often than not consider the scenarios that face the competing demands from the urban environment. This is why this model should and will consider these two demands conjunctively.

In regards to the dynamic relationships that are present within the water balance cycle of a catchment with a range of landuses, these relationships are generally controlled by due to either positive or negative feedback processes. Positive feedback is defined whereby the effect on changing the input variable on the output actually creates a loop of greater effect on the input variable than the initial variation. To give an example of this in water balance terms, by increasing the total demand of water, increases the output of recycled water, which if made available could increase the demand of water for outside use. Processes like these will be detailed within the model.

2. CASE STUDY: THE SOUTH CREEK CATCHMENT

The South creek catchment (Figure 1) of Western Sydney (620 sq km) is an interesting case study for this project. South Creek is a major tributary of the Hawkesbury-Nepean River that runs for over 64 kilometres in a generally northerly direction from where it rises in low hills near Narellan through the Western Cumberland Plaint to Windsor. The major tributary to the South Creek is the Eastern Creek which joins South Creek near Riverstone. The other larger tributaries include Kemps, Ropes and Rileys creeks. It contains the typical rural landscape and irrigated water demands as well as an increasing urban spread. It makes it an ideal case study as it contains all three major landuses (including natural) that demand water within catchments and the different landuse change and water supply scenarios that could evolve in the future.

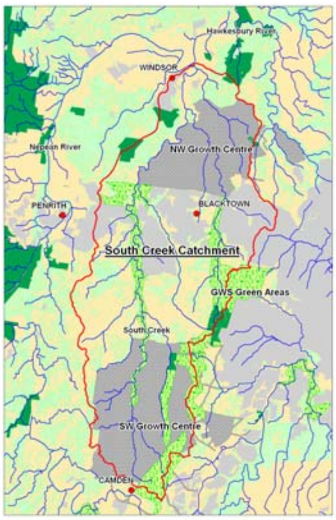

Figure 1. South Creek catchment overview and proposed growth regions

Figure 2. Annual precipitation spatial variability

Annual rainfall distribution over the south creek catchment is depicted in figure 2. This figure was created using the rainfall recorded between 1970 and 2006. According the figure, western part of the catchment is wetter than the middle and lower part of the catchment. Maximum annual rainfall of the catchment is about 860 mm where as the minimum is about 725 mm.

2.1. Population Trends and Catchment Policy

Currently, the New South Wales planning structure is set up in such a way that the State government identifies potential areas of development and local councils then go onto identify in more detail areas that could be developed and rezoned for residential purposes. Currently the New South Wales State government has identified 2 areas within the south creek catchment as potential 'growth centres' in its draft sub regional strategies reports; identified as North West and South West Growth Centres as seen in Figure 1. These will provide increased future urban water demand

2.2. Potable and Non-potable Water Use

As of 2008, th annual potable water use in the catchment is approximately 40,000ML. Current non-potable water use in the catchment is only a fraction of the potable water consumed. Currently, there is 9,314 ML of non-potable water used for agricultural irrigation each year and 2,797 ML for urban activities (Figure 3), totaling about 12,112 ML. Thus currently the use of non-potable water in the catchment, which is mostly via licensed extractions from the South creek catchment's watercourses, is only around 25% of the total potable water consumed in the whole catchment. Monthly metered unban potable water use is depicted in figure 3.

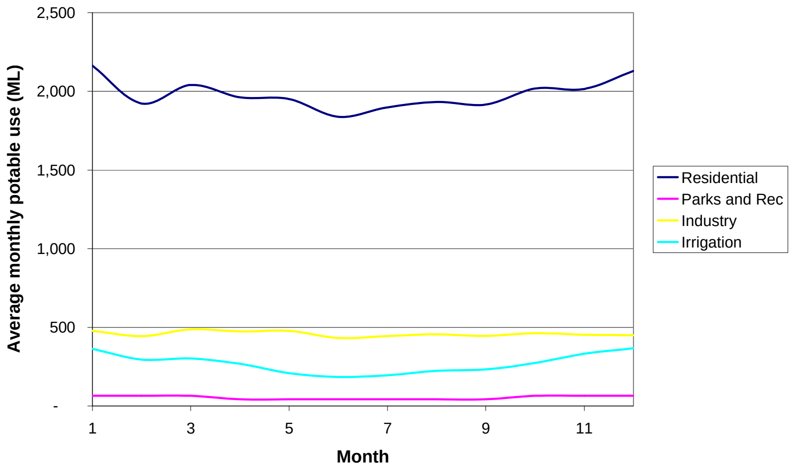

Figure 3. Monthly metered urban potable water use

2.3. Land Use

Land use in the catchment as is characterised in Figure 4, and can be classified as a peri-urban environment. This research investigates how the future land use change in the catchment will affect the future demand for water and how the supply of the water will also be affected by the demand and climatic change scenarios. As the region urbanises the demand for water will increase. Storm water runoff will also increase due to decrease in permeable area. Therefore total flows in the catchment will change in the future. The actual effect that predicted urbanisation and population changes will have on the catchment will be investigated further using the VENSIM model.

As can be seen in by analysing the rainfall distribution figure (Figure 2) and the landuse portraying where the urban areas in the catchment are (Figure 4), we are likely to see runoff in the east portion of the catchment to be higher than west part as there is a high amount of urbanization in the region where the highest rainfall is found. This is due to the higher permeability areas of urban regions causing most of the rainfall in these regions to go to runoff.

Figure 4. Landuse characteristics of the South Creek catchment

3. MODEL DEVELOPMENT

The generic catchment model was created considering supply and demand variables as well as landuse characteristics. Dynamic nature of the interdependent variables affecting the water cycle was incorporated using System Dynamic modeling techniques. The primary objective of the model is to simulate future supply and demand scenarios of a catchment to understand possible future water security problems, especially in the case of a catchment with changing landuse patterns. The developed model can be use to study possible integrated solutions to future water security issues and their likely effectiveness.

3.1. Model Outline

The model (Figure 6) is essentially set up such that, in a broad sense, it has the ability to reproduce the dynamic influences between the supply and demand pressures on water for most catchments now and into the future; this is one of the objectives of and the basic founding block of the model. It is then the focus of the model to identify future scenarios that could take shape in the catchment and also possible opportunities to help create a more sustainable future water plan. It is essential to understand that although it is the objective of this model to identify possible opportunities that could be considered, it is not the objective and thus not included in the structure of the model to consider how these opportunities could be taken advantage of. In this sense, this is its weakness, being that the use of the water depends on the location of the possible receiver and its quality, and this consideration is not adequately considered in this model.

3.2. Supply and Demand Scenarios

The prediction of supply scenarios will come from considering the effect of climate change on the supply of water in the future, with differing effects of severity, as well as the scenario whereby the climate returns to or stays at average climate conditions. These climate influences on supply will be coupled with the dynamic influence that landuse change (demand change) can also have on supply, particularly in regard to changes in runoff.

The demand scenarios (Table 1), like the supply scenarios, will cover a suitable range of possible future outcomes that the catchment could face, and thus capture some of the sensitivity analysis of the model. There are three classes of demands that make up the total demand in this model; being irrigation, urban (3 subsets) and environmental. How these current demands are predicted into the future is crucial to the model giving accurate outputs. The current demands are based on obtaining the appropriated data from the appropriate sources. The future demand predictions for the three competing demands can be approached in many ways. In this project the future demands can be seen in the table below, with urban demand linearly dependent on population growth.

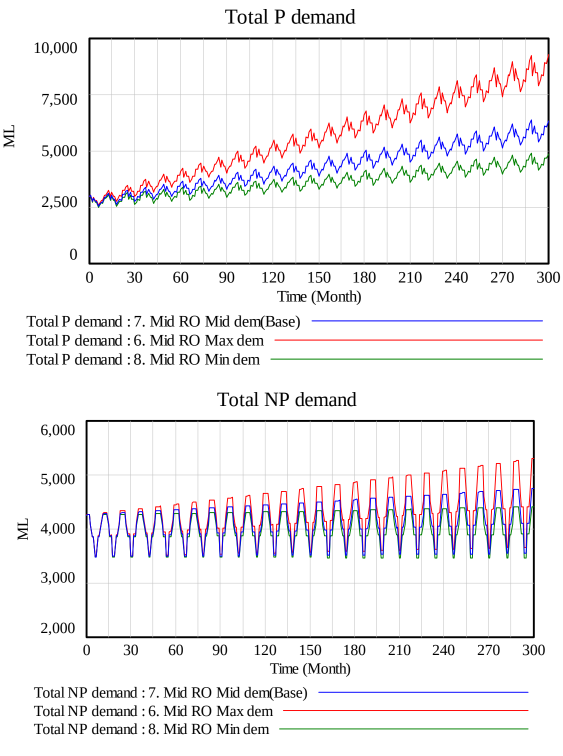

Figure 5. Potable and non-potable demand scenarios run in model

Table **1**. Demand scenarios run in model

Demand:25 years time	**Scenario**	**Scenarios to be run:**
Urban (Res, Parks, Indus)	Min population migration scenario	Population to increase by 25%
	Middle of road population migration scenario	Poulation to increase by 100%
	Max population migration scenario	Population increase by 200%
Irrigational	Min entitlement scenario	A decrease in entitlements by 15%
	Middle of road entitlement scenario	No change in entitlements
	Max entitlement scenario	An increase in entitlements by 15%
Environmental	No change in environmental demand	No change in environmental demand

3.3. The Model

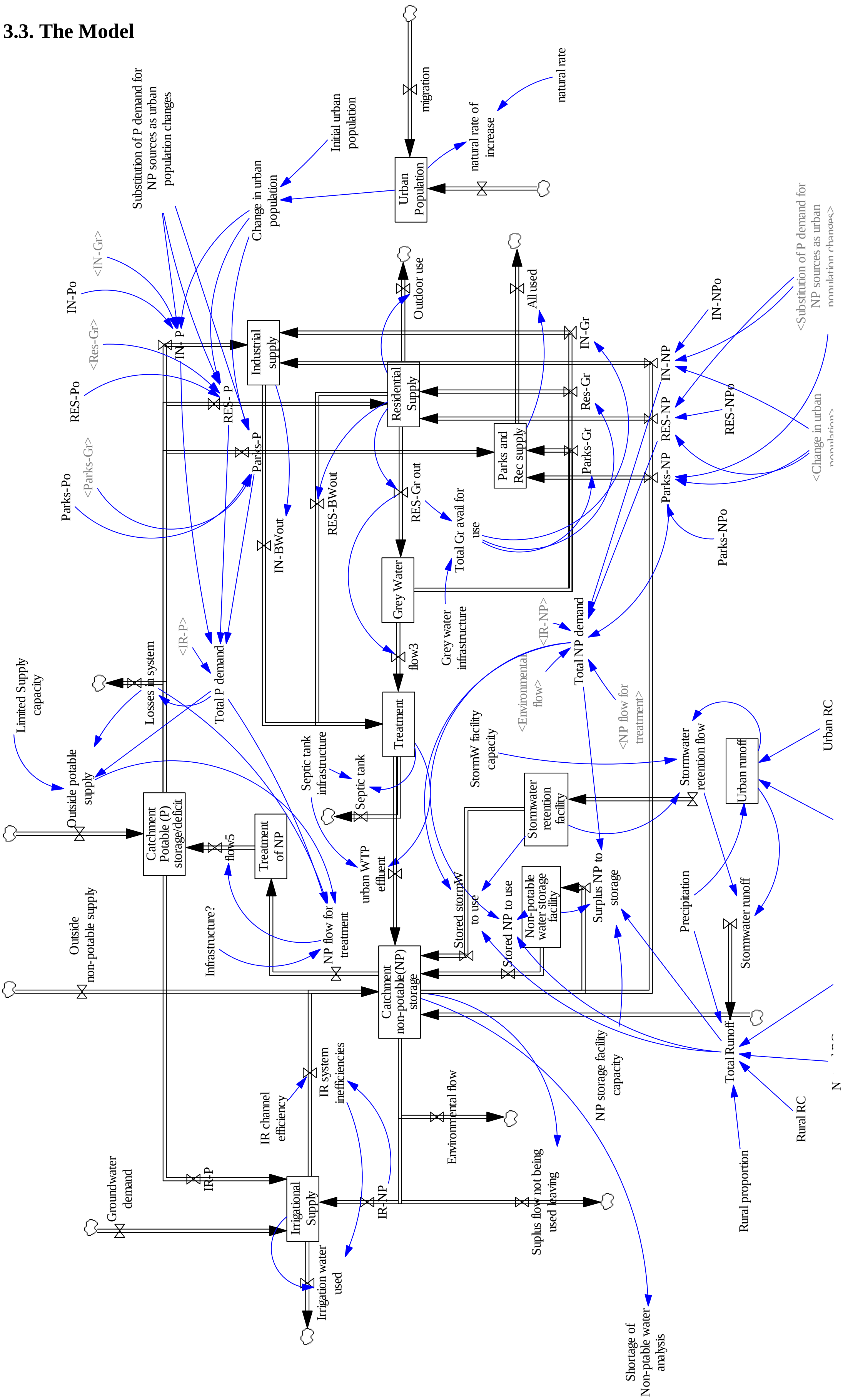

Figure 6. The schematic representation of the VENSIM model developed

4. RESULTS

The results demonstrate a trend that as water demand increases in the scenarios run for the South Creek catchment, the catchment's non-potable supply would be less effected (greater storages) under the different climate scenarios that could eventuate. This is due to urban landuse expanding, under the increasing demand scenarios, which in turn creates a higher proportion of the catchment with a higher runoff coefficient, which dynamically affects the supply. It is no surprise that the minimum runoff climate change scenario created the higher stress on the catchment's non-potable reserves. But the shortage of non-potable water resources does not happen that often and is less than the environmental flow requirement stipulated in this model, and there is still significant 'surplus' flow leaving the catchment not being used.

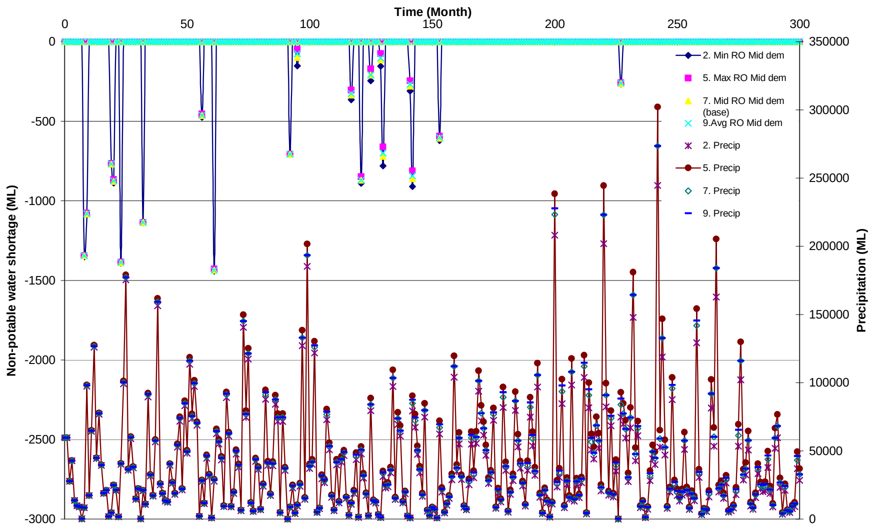

Figure 7. Non-potable shortages under base (mid) demand scenario and changing precipitation/climate scenarios

The below figure shows us that generally in the future, there is a low probability of the catchment's non-potable resources being under severe stress under all the scenarios considered. Under the base scenario, the catchment is likely to only face non potable shortages 8% of the time, with this always being less than the total environmental demand (3,000 GL). But this of course depends on the assumption that the catchment does not have to source or replace a portion of its potable demand with the catchments own non-potable supplies. The effect that the potable supply coming into the catchment being limited and the catchment having to replace some of the potable demand shortage with its own resources was something tested, and it was still found to not have a severe effect on the catchments non-potable storages.

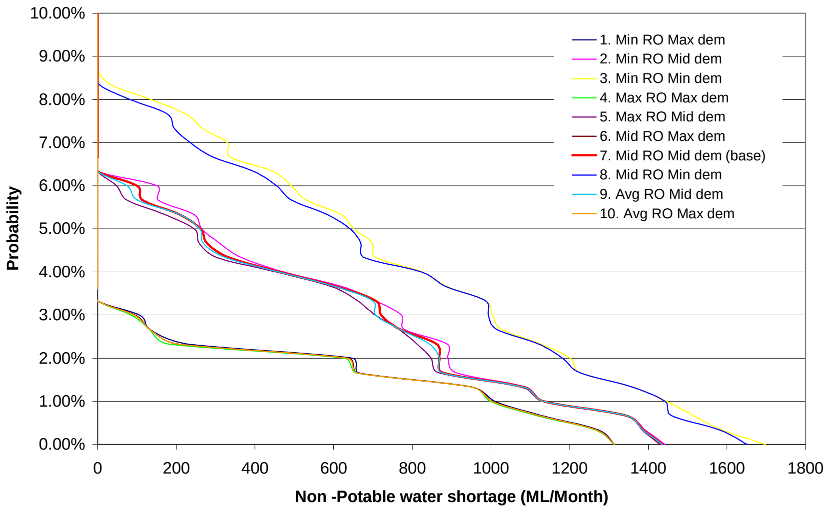

Figure 8. Probability under each scenario run that at anytime during the simulation that the catchment will have a non-potable water shortage

5. DISCUSSION AND CONCLUSIONS

The conclusions on the water security of the South creek catchment have been achieved through the development of a water supply and demand model that is both a structural representation of the water cycle and also a model that considers the dynamically interdependent variables within and effecting the cycle. A model like this helps all competing water uses understand their likely position and involvement in the catchment now and into the future, as well as possible integrated opportunities available to the catchment.

It is demonstrated in this paper that, through the development and application of a model that can cope with system dynamic variables, the South Creek catchment's future water security is likely to be generally secure. The scenarios also lead us to conclude that there is the possibility of increasing irrigation activities in the region in the future, especially if it was coupled with urban expansion. These conclusions also rely on the ability of the outside potable supplies to meet the demands of the South creek catchment, which of course may not be the case. But in looking at the implications of a scenario that limits the incoming potable supply (with the outside potable supply being limited to 150% of current supply), it would seem that the catchment should still be able to supply its total water demands (both potable and non-potable) through both the outside potable supply and the catchments own non-potable resources without severely affecting its water resources.

The conclusions drawn from the model are obviously focussed on the quantity of the water and not the quality or location of the water. This was not a focal point of this model, but future analysis of solutions to water security dilemmas should consider these variables as well as social and economic factors as well.

The model developed achieved all its objectives, but future improvement could be an option. The calibration of the model against other catchments could be undertaken, and the model changed accordingly. The method for the calculation of the runoff could be modified to a more accurate method, but would have to be done so as to still pick up on landuse change dynamic effect on runoff. And finally the irrigational demand could be furthered technically as dynamically dependent on the climate variables and crop requirements. But regardless of the further development of the model, the current model should still give catchment water managers an idea of the future conditions and opportunities that could face them, which is a very valuable tool.

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