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KATAWARE: A NEGOTIATION-SUPPORT TOOL FOR PARTICIPATORY WATER RESOURCE MANAGEMENT IN THE KAT RIVER VALLEY

PROTOTYPE MODEL

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STEFANO FAROLFI & BRUNO BONTE'

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KatAWARE: Prototype MODEL

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Terminology and Acronyms

AWARE	Action research and Watershed Analyses for Resource and Economic Sustainability
ComMod	Companion Modelling
Cirad	the ‘Centre de coopération internationale en recherché agronomique pour le développement’
CORMAS	Common Pool Resources and Multi Agent Simulation
DWAF	Department of Water Affairs and Forestry
IWR	Institute for Water Research
KRWUA	Kat River Water User Association
MAR	Mean Annual Runoff
MAS	Multi-Agent System
NWRS	South African National Water Resource Strategy
GIS	Geographic Information System
UML	Unified Modeling Language
WRC	Water Research Commission

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Preface

Within the Water Research Commission (WRC) project: 'A stakeholder driven process to develop a Catchment Management Plan for the Kat River Valley', a process of participatory water resource management was initiated by the Institute for Water Research (IWR) and the Geography Department at Rhodes University (Burt, 2005).

An integral part of the participatory process is the development of a negotiation-support tool, which will enable local water management institutions i.e. the Kat River Water User Association (KRWUA) to discuss future development scenarios in relation to water allocations. The scenarios simulate the possible outcomes in terms of water relations between the different sectors in the catchment, and the consequences of these relations n economic, social and environmental outcomes.

KatAWARE is a Multi-Agent System (MAS) being developed through a participatory action research approach called Companion Modelling (ComMod). According to this approach an iterative process of modelling and discussion takes place between the research team and the local stakeholders resulting in preliminary versions of the model. From these preliminary versions, the model evolves into a prototype version that is not necessarily more complex, but which best describes the stakeholder's reality as expressed by them through the participatory process.

This report provides a thorough description of the KatAWARE prototype model. The report is organised in seven chapters: The first chapter is a general introduction of the model's framework and of the adopted modelling approach; chapter 2 describes the model's structure; chapters 3 and 4 provide an illustration of how the water demand and water supply components of the model have been calibrated; chapter 5 shows agents' evolution rules and defines the scenarios obtainable through the KatAWARE prototype; chapter 6 gives and overview of the model outputs; chapter 7 discusses the user interfaces.

1. KatAWARE: A MULTI-AGENT MODEL TO REPRESENT WATER SUPPLY AND WATER DEMAND DYNAMIC

KatAWARE is a multi-agent model co-developed with local stakeholders during an iterative and participatory modelling process (the ComMod Research team, 2005). Multi-agent modelling is a powerful way to represent and simulate multi-stakeholder activities in respect to the interactions between themselves and their environment (Ferber, 1995). It provides a means of representing a complex system made up of sets of agents interacting among themselves within a designated environment. Each agent's perception will be based on his interactions with his environment and the associated goals he has in relation to its development (Figure 1.1) (Bonté et al, 2005). These perceptions will form the basis for the communication between agents and the decisions that need to be reached in order to enable all agents to achieve their goals within their shared environments (Figure 1.1).

Cirad (the 'Centre de coopération internationale en recherché agronomique pour le développement') has adopted this modelling approach to facilitate the generation of understanding amongst local stakeholders about resource dynamics, concerned in management decisions, within a participatory modelling setting.

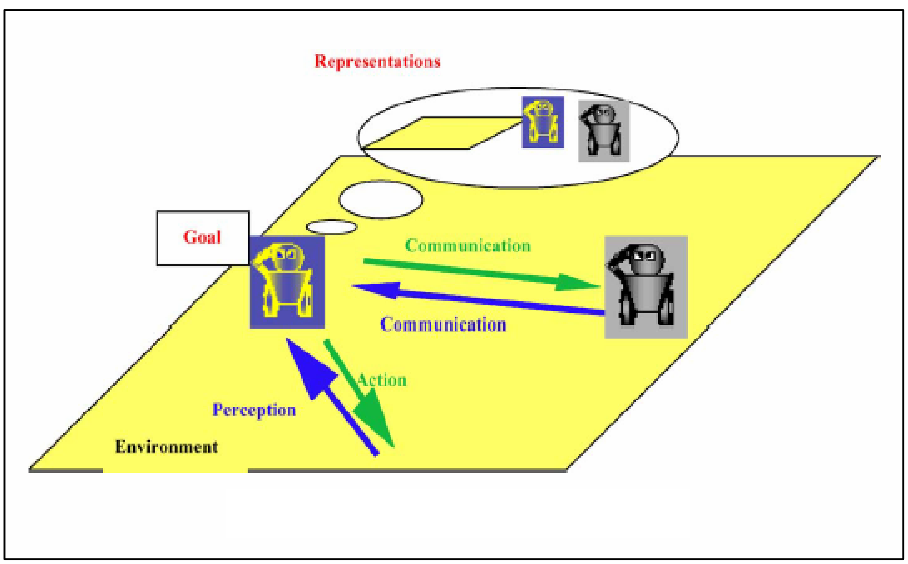

Figure 1.1 **A representation of the philosophy behind a multi-agent model (Bonté et al, 2005; adapted from Ferber, 1999).**

The KatAWARE prototype was built using the 'CORMAS' (Common Pool Resources and Multi Agent Simulation) modelling platform[1]. This computer platform provides the basic framework for the multi-agent model (agents, topologic background, objects and time scheduling), and allows the modeller, specialising and organising it, to build his own specific multi-agent model (Le Page & Bommel, 2004).

The prototype is a new generation of the AWARE (Action Research and Watershed Analyses for Resource and Economic sustainability) model described in: Farolfi & Hassan, 2003 and Hassan & Farolfi, 2005. Although the two models are radically different in their structure and functioning, KatAWARE shares the same philosophy and calculates the same kind of outputs as AWARE.

Therefore, the KatAWARE prototype enables the representation of water demand and water supply in a catchment at different spatial and temporal scales. 'Water demand' is the amount of water required by the agents and 'water supply' is the amount provided by the environment. The model focuses on social, economic and environmental consequences of alternative strategies of water allocation between the different water user sectors in the Kat River catchment.

[1] Information about CORMAS and its applications are available on the Cormas website (http://cormas.cirad.fr/).

2 PROTOTYPE MODEL STRUCTURE

2.1 KatAWARE Prototype's Framework

2.1.1 KatAWARE Prototype's Entities[2]

2.1.1.1 Spatial Entities/Units

Spatial entities or units provide the topologic background of the model; they constitute the model's space. In multi-agent models space is the basis for the articulation of agents' interactions, among themselves and with the passive entities. In KatAWARE, and in most models developed in CORMAS, a natural renewable resource (here water) represents the passive entities.

We will see in this section how spatial entities allow for the representation of geographical issues and relations between the agents and the resource. Therefore, to represent space in the KatAWARE prototype the Kat River catchment surface (about 1700 Km^2) was divided up in a grid of 76x61 cells of about 66, 5 ha each. On the basis of this grid the spatial environment of the agents was defined relative to spatial units composed of sets of coinciding grid cells.

The only functional spatial unit in the prototype is the quaternary S*ub-catchment,* which is a hydrological spatial unit (DWAF, 2001). However, for calibration and observation purposes, two other spatial units were considered: the *Ward* (the elementary administrative unit in South Africa), and the V*oting Area (as identified by* Motteux, 2002, in the selection of KRWUA representatives) (Figure 2.1).

[2] These definitions correspond to object oriented programming language's '*Classes*' here indicated in italic font and a capital letter; attributes of these classes are indicated in italic font (Figure. 2.2)

A. *The Sub-catchment*

The S*ub-catchment* supplies the resource. The only way agents can have access to water is by withdrawing it from the *Sub-catchment* they belong to. A given S*ub-catchment* is defined during the initialisation phase by the following characteristics[3]:

- *Yearly self yield*: The amount of water brought in the system by this single *Sub-catchment* each year.
- *Monthly distribution*: The repartition of the yearly self yield for each month of the year.
- *Upstream Sub-catchments*: Other S*ub-catchment/s* situated upstream of a selected *Sub-catchment* which directly contribute to its flow each month.
- *Downstream Sub-catchment*: Other Sub-catchment*/s* that is/are downstream of a selected *Sub-catchment* and to which this *Sub-catchment* directly contributes to their flows each month.
- *Occupants*: Situated entities present in a *Sub-catchment*. The only two situated entities, of the KatAWARE prototype, are *Farms* and *Villages, as* described later.

It is important to note that all water withdrawals from the source (*Sub-catchment*) must occur via its occupants (*Farms* or *Villages*).

B. *The Ward*

The W*ard* corresponds to the smallest administrative unit in South Africa. A division of the space into Ward*s* allows the modeller to take this spatial unit into consideration in terms of water demand and socio-economic outputs.

[3] Another characteristic is included in the UML class diagram presented in Figure. 2.2, namely: *water availability*. It doesn't define the *Sub-catchment* but is a functional characteristic allowing the transfer of the resource from upstream *Sub-catchments* to downstream *Sub-catchment* once the water used by upstream users has been withdrawn from the system.

C. The Voting Area

The *Voting Area* is also an administrative spatial unit and has the same role of the Ward in the model. It corresponds to the Voting Areas designated for the selection of representative water users on the KRWUA (Figure 2.1).

2.1.1.2. Social Entities/agents

Two types of social entities or agents coexist in the KatAWARE prototype model; these correspond to the main water users of the Kat River catchment. One represents domestic uses, namely the *Village*; and the other represents agricultural uses (irrigation), namely the *Farmer*.

- On the one hand, the *Village* is a 'situated entity' (*occupant*) that belongs to a *Sub-catchment*. As an *occupant*, it withdraws water directly from it.
- On the other hand, the *Farmer* is not situated and its water consumption is performed via a *Farm* that is the farming 'situated entity' (*occupant*) which belongs to a *Sub-catchment*.

2.1.1.3 Passives Entities

Other entities present in the prototype either describe the *Village*, the *Farmer* or the *Farm*. Their articulation and conceptual characteristics are presented in the Unified Modelling Language (UML) class diagram in Figure 2.2. Their respective functioning is explained in the chapter 4 describing the water demand in KatAWARE.

2.1.2 KatAWARE Prototype Initialising

During the initialisation phase all data required for the development of the before mentioned entities was collected and calibrated. Then, GIS maps are used to draw the spatial entities (*Sub-catchments*, *Wards* and *Voting Areas*) and to provide topographical support to the placement of the situated entities (*Farms* and *Villages*).

To represent the social and passive entities in the model, a series of hypotheses are made. These hypotheses further developed through the participatory process.

2.1.3 KatAWARE Prototype Scheduling

Temporal settings representing scenario progress occur over two time-frames/steps:

- Monthly step – through which the **hydrological situation evolves**;
- Yearly step – during which **socio-economic decisions are taken**.

Chapter 5 presents the KatAWARE scheduling with reference to the UML sequence diagrams in Figures 5.1 and 5.2.

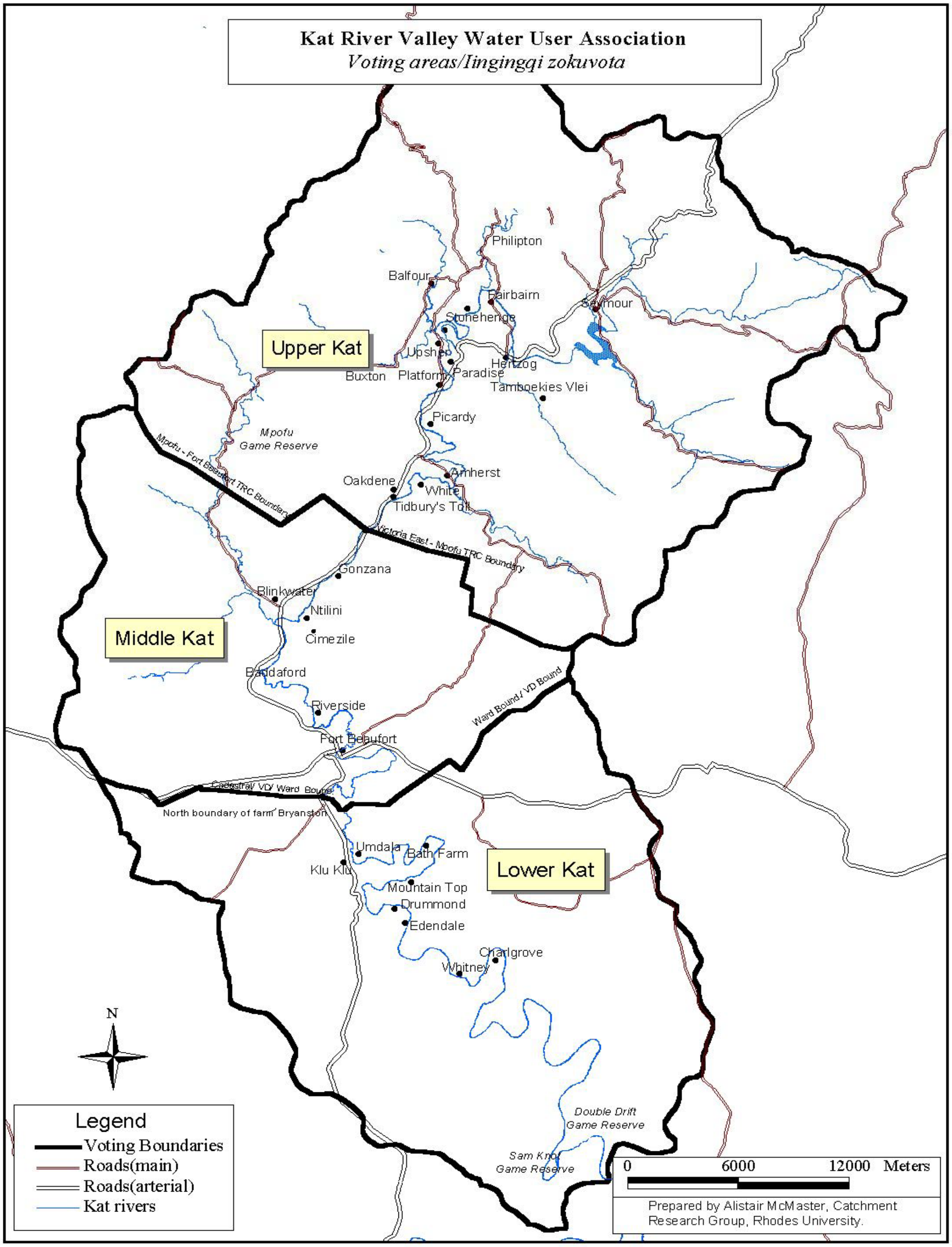

Figure 2.1 **The Kat River catchment and its Water User Association *Voting Areas*: Upper, Middle and Lower Kat.**

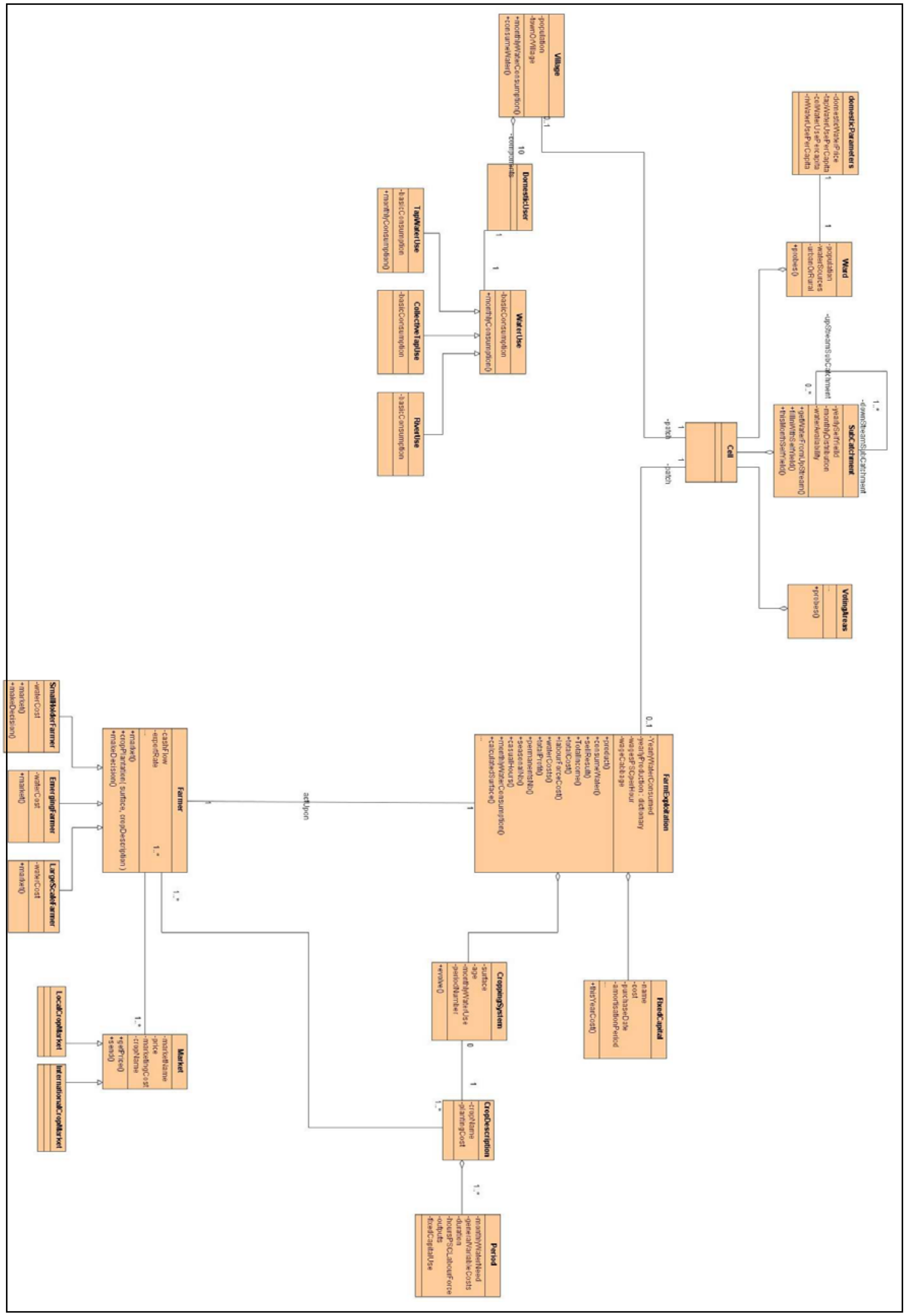

Figure 2.2 KatAWARE prototype United Modelling Language (UML) 'Class' diagram.

2.2 KatAWARE Prototype Representation of Water Supply and Demand

2.2.1 Water Demand

Each water user agent uses water via a situated entity. The V*illages* use water directly and the *Farmers* use water via their *Farm*. At the beginning of each simulated year the socio-economic choices made by each agent define both the *yearly water demand* and the *monthly distribution* of this demand over a year. (Equation 2.1).

Therefore, for a given year (*Y*) 'i' at a given month (*M*) 'j', water demand (*d*) of a given user (*U*) 'k' can be expressed as follow:

$$Ud_{kij} = Yd_{ki} \cdot Md_{kj} \qquad [2.1]$$

Where:

Ud_{kij} = 'k' user's water demand, year 'i', month 'j'

Yd_{ki} = 'k' user's yearly water demand of year 'i'

Md_{kj} = 'k' user's monthly distribution for month 'j'

Remembering that all water uses are performed via situated entities; water demand of each S*ub-catchment* is then calculated by summing up all the water demands occurring in this S*ub-catchment*. (Equation 2.2)

For a given year 'i' at a given month 'j', water demand of a given S*ub-catchment* 's' can be expressed as follows:

$$Sd_{sij} = \sum_{k \in (Us)} Ud_{kij} \qquad [2.2]$$

Where:

Sd_{sij} ='s' S*ub-catchment*'s water demand, year 'i', month 'j'

(Us) = users of 's' S*ub-catchment* index set

Ud_{kij} = 'k' user's water demand, year 'i', month 'j', calculated as explained previously

2.2.2 Water supply

2.2.2.1 The Catchment Scale: 'supplying the system'

In every scenario of the KatAWARE prototype, the yearly water supply provided to the whole system is constant year after year during the whole simulation. This supply is shared among the model's *Sub-catchments*. Each *Sub-catchment* brings each year a specific amount of water to the system (namely: *yearly self yield*) distributed over the year in a specified *monthly distribution*.

Therefore, the amount of water brought to the whole system each month can be calculated as the sum of the self yield of each *Sub-catchment* as following (Equation 2.3). It remains unchanged each year.

$$Cs_j = \sum_{s \in (Sc)} Yss_s \cdot Ms_{sj} \qquad [2.3]$$

Where:

Cs_j = Whole catchment's water supply for month 'j'

(Sc) = System's *Sub-catchments* index set

Yss_s = Water brought each year to the system by *Sub-catchment* 's' (*yearly self yield* of *Sub-catchment*)

Ms_{sj} = 's' *Sub-catchment's* monthly distribution of annual yield at month 'j'

2.2.2.2 The Sub-catchment Scale: 'water demand of some has an impact on water supply of others'

Water supply to a given *Sub-catchment* is provided by two sources:

- The self yield, representing the water brought through rainfall as the *yearly self yield* described previously.
- The water flowing from *upstream Sub-catchments*, representing water already present in the system and flowing through the river.

Each month the amount of water ‘flowing from upstream’ is summed up to the ‘self yield’ to obtain the *water availability* that would be available for the users of a given *Sub-catchment* (Equation 2.4).

Therefore, for the year ‘i’ at month ‘j’, *water availability* of a given *Sub-catchment* ‘s’ (corresponding to the water supply at the *Sub-catchment* scale) can be expressed as following:

$$Ss_{sij} = Yss_s \cdot Ms_{sj} + \sum_{u \in (Su)_s} O_{uij} \qquad [2.4]$$

Where:

Ss_{sij} = *Sub-catchment* ‘s’ total supply for year ‘i’, month ‘j’

Ys_{ss} = *Sub-catchment* ‘s’ *yearly self yield*

Ms_{sj} = *Sub-catchment* ‘s’ *monthly distribution* at month ‘j’

$(Su)_s$ = *Sub-catchment* ‘s’ *upstream Sub-catchments’* index set

O_{uij} = *Sub-catchment* ‘u’ outflow for year ‘i’ month ‘j’ (Equation 2.5)

With:

$$O_{uij} = Ss_{uij} - Sd_{uij} \qquad [2.5]$$

Where:

Ss_{uij} = *Sub-catchment* ‘u’ total supply for year ‘i’ month ‘j’ as defined previously

Sd_{uij} = *Sub-catchment* ‘u’ water demand, year ‘i’, month ‘j’ as defined previously

From these equations it should be observed and noted that, water supply in each S*ub-catchment* is not the same each year, but depends on the water demanded in *upstream Sub-catchments* every year according to users' socio-economic choices.

2.2.3 Balance

Balance between water supply and water demand can then be observed both at the catchment scale or the sub-catchment scale. Working at these scales enables the analysis of spatially focused water stresses in the catchment, according to socio-economic choices and evolution of the different agents. (Equations 2.6 and 2.7).

For each month 'j' of each year 'i', the catchment water balance can be expressed as following:

$$Cb_{ij} = Cs_j - \sum_{k \in (Uc)} Ud_{kij} \qquad [2.6]$$

Where:

Cs_j = catchment supply for month 'j' (as defined previously)

(Uc) = users of the catchment index set

Udkij = user 'k' water demand for year 'i' month 'j'

And, for each month 'j' of each year 'i', *Sub-catchment* 's' balance can be expressed as follows:

$$Sb_{sij} = Ss_{sij} - Sd_{sij} \qquad [2.7]$$

Where:

Ss_{sij} = *Sub-catchment* 's' total supply for year 'i' month 'j' as defined previously

Sd_{sij} = *Sub-catchment* 's' water demand, year 'i', month 'j' as defined previously

From the above equations it is important to notice that if water supply > water demand, the balance corresponds to the *Sub-catchment* outflow (Equation 2.8):

$$O_{sij} = Sb_{sij} \qquad [2.8]$$

3. CALIBRATION OF WATER SUPPLY

Water supply is represented using the Department of Water Affairs and Forestry's (DWAF) concepts and adapted values for yield and mean annual runoff (MAR). These concepts are defined by DWAF as laid out in appendix D of the South African National Water Resource Strategy (NWRS) (DWAF, 2004):

- **Yield**: *'Water that can reliably be withdrawn from a water source at a relatively constant rate'*.
- **MAR**: *'the total quantity of surface flow, which on average originates from a certain geographic area annually'*.

The yield is calculated as a proportion of the MAR for different levels of assurance of supply. Due to the erratic and unreliable nature of river flow in South Africa, only a small portion of the MAR is available as yield in its natural unregulated state. For this reason, at the same assurance of supply, yield can be remarkably increased if storage of water is possible. The only other factors able to increase yield are the transfer of water from one catchment to another and the possibility to use groundwater. In fact, groundwater use may have an impact on surface water availability, nevertheless water available as practical usable yield can be increased by groundwater access considering that groundwater sources have a temporal variation much smaller than surface water.

For the implementation of the NWRS, DWAF chose to use a yield at a level of 98% assurance of supply, corresponding to the yield users are ensured to dispose of at least 49 years out of 50 (DWAF, 2004). It was chosen to work with the same level of assurance in the KatAWARE prototype model.

To represent water supply in the KatAWARE prototype, the Kat River catchment was divided into 6 *Sub-catchments* as shown in Figure 3.1 (WR 90, 1990). These *Sub-catchments* correspond to the DWAF's quaternaries (Q94A to Q94F) defined for the Q94 tertiary sub-catchment (the Kat River catchment) in the NWRS. Yearly yields of each *Sub-catchment* (*yearly self yields*) have been calculated from data available from DWAF in the following way.

DWAF estimates the Kat River catchment total surface water yield at 98 % assurance of supply corresponding to 23 million m^3/a, of which 12.7 million m^3/a come from the Kat River Dam situated in the Q94A *Sub-catchment* (DWAF, 2001). The total groundwater use of the catchment is estimated as 0.1 million m^3/a in the same document, but given its insignificant amount it has not been considered in this model.

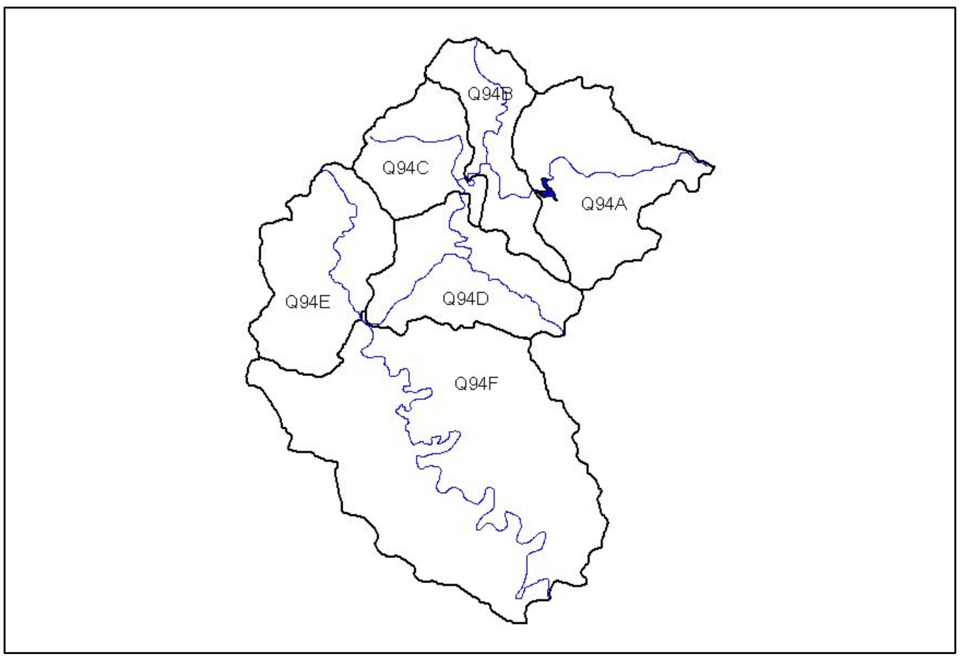

Figure 3.1 Kat Quaternary Sub-catchments and river (WR90).

Because the yearly yield of each quaternary was not available from DWAF, it was estimated using the following method. First, quaternary Q94A's yearly yield was set at 12.7 m^3/a, assuming that the total yield from the Dam was available for the *Sub-catchment's* users. Second, the remaining yearly yield of the Kat River was distributed to the other *Sub-catchments* proportional to their respective MAR. Table 3.1 presents the distribution of the yearly yield between the Kat River's quaternary *Sub-catchments*.

Table 3.1 **Calculation of the yearly yields of the quaternary *Sub-catchments* in the KatAWARE prototype.**

	A	B	C	D	E	F	Total
Incremental MAR (m3/a):	23,57	10,21	11,33	7,45	9,28	8,19	70,03
% of MAR	53,88%	22,17%	22,17%	22,17%	22,17%	22,17%	note 2
KatAWARE yearly yield (m3/a):	**12,7**	**2,26**	**2,51**	**1,65**	**2,06**	**1,82**	**23**
Cumulative yield (m3/a):	*12,7*	*14,96*	*17,48*	*19,13*	*2,06*	*23,00*	

Note 1: In grey are the data available from DWAF (DWAF, 2001) other ones are calculated

Note 2: same percentage of MAR is used to calculate quaternaries B to F's yield

It was decided that the *monthly distribution* of the yearly yield for each quaternary would be the same, with the exception of Q94A where releases from the Dam are assumed to be controllable. The distribution for Q94B to Q94F was calculated from the WR90 data (WR 90, 1990). Values used are calculated as an average of the Kat River catchment's simulated rainfall distribution between 1920 and 1990 (Table 3.2 and Figure 3.2). Due to insufficient information on the Dam release procedures it was assumed that the Dam would act as a buffer against significant yield changes to Q94A; therefore, the yearly yield is considered to have a constant distribution over a twelve month cycle.

Table 3.2 **Average *monthly distribution* of rainfall in the Kat River catchment (WR90, 1990).**

***Monthly distribution* of rainfall to the tertiary catchment Q94: Kat River catchment**													
	OCT	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	***TOTAL***
Ave rainfall values (mm)	5.93	9.22	8.74	5.79	7.54	13.45	6.9	3.56	2.04	2.16	3.48	3.36	***72.17***
% of year supply	**8.22**	**12.78**	**12.11**	**8.02**	**10.45**	**18.64**	**9.56**	**4.93**	**2.83**	**2.99**	**4.82**	**4.66**	***100.00***

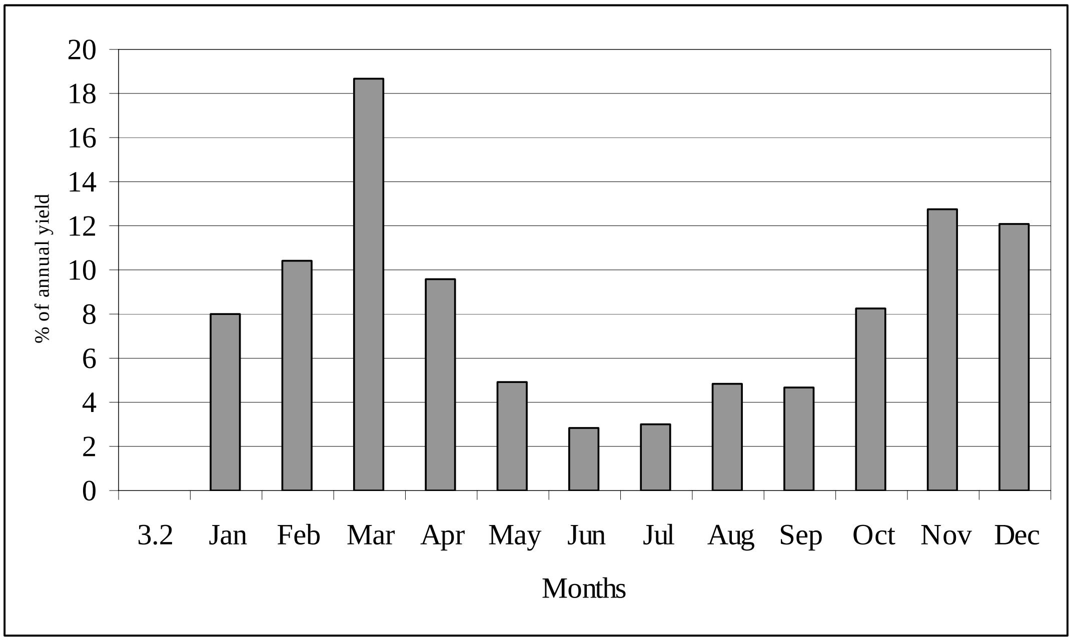

Figure 3.2 ***Monthly distributions*** **(as percentage of average annual yield) of rainfall in the Kat River catchment.**

4. CALIBRATION OF WATER DEMAND

4.1 Introduction

As previously indicated water demand in the KatAWARE prototype is represented by agents' water needs. There are two groups of water users represented in the prototype these are: domestic users and irrigators (farming). As explained previously Domestic users are represented as *Village* agents and farming agents function through the management of *Farms*.

To represent the real water users in the Kat River catchment, the following entities were distributed within the created spatial entities/units.

- 49 530 'inhabitants' were distributed in 93 *Villages.*
- 1 356 'ha' were distributed in 36 *Farms* each managed by a *Farme*r.

4.2 Domestic Users

4.2.1 Entity responsible for domestic uses: the Village

The Domestic users in the prototype are represented through the *Village* entity, which acts as an 'agent' in the multi-agent model. Most of the data available about domestic uses in the Kat River came from the Statistics SA Census database (Farolfi and Jacobs, 2005) and are dealt with at the Ward scale. However, the *Village* scale is much more consistent with the idea stakeholders have of their distribution in the catchment. This is the main reason why it appeared necessary to adapt the data available to this scale for the prototype. Hopefully this data will be enriched later by primary data gathered by the research team through field surveys and workshops.

Furthermore, the population of the Kat River catchment is concentrated in specific areas, therefore, the spatial unit of a *Ward* does not effectively represent the population partitions; particularly if one wants to observe the interactions Domestic users have with the resources (river and storage facilities) and with the other users.

Each *Village* is defined by the following characteristics:

- Its *population*;
- Its composition in terms of water users (Section 4.2.2);
- A statement that is defined as *urban* or *rural*, which reflects indicators having an impact on water uses, such as access to sanitation facilities etc. (Farolfi, Jacobs, 2005).

Water consumption of each *Village* has been calculated according to these characteristics.

4.2.2 Different types of Domestic Uses

Three different types of uses have been identified to describe domestic uses in the Kat River catchment: r*iver water use*, c*ollective tap water use* and i*ndwelling tap water use*. They refer directly to the 'water source' the user is supposed to have access to. In fact, while other households' characteristics have an impact on water consumption, the amount of water used per capita seems to be highly correlated to the source of water used (Banda et al., 2004). According to these authors, the amount of water a household consumes depends on the frequency of trips to fetch water, which is a function of the type of water source the household members can access.

For each type of water source, it was decided to consider constant water consumption during the year. This means that the seasons have no impact on the modelled domestic consumption. This choice is mainly motivated by a lack of data and by the fact that domestic consumption represents a little part of total consumption. However, this will need to be calibrated further in the future. Further analysis in the Kat River catchment indicated that domestic uses follow a specific pattern over the year due to climatic and cultural factors.

The different types of water uses can be described as following:

4.2.2.1 River Water Use:

This category includes users who do not have access either to collective taps or to indwelling taps. The water source used by these users is mainly direct withdrawing from the river, but can also be a water vendor, although this type of domestic water provision has proved marginal in the studied areas. Users represented by this category are the ones with the less stable access to the resource and consequently the ones with the lowest consumption.

Water consumption by this type of user will be very rigid to most changes. On the one hand the limited amount of workforce to fetch water limits its consumption, and on the other hand households put all their efforts in maintaining the current consumption level – which is below the Basic Human Needs as defined by the New Water Act (RSA, 1998). Therefore, water consumption by this group of users is considered constant in the whole basin at 0.7m^3/capita/month. This value comes from primary data collected in another basin: the Steelpoort sub-basin in Limpopo province (Banda et al., 2004). This amount corresponds to 23.3 L/d/capita which is lower than the 25 L/d/capita set as the Basic Human Need's criteria.

4.2.2.2 Collective Tap Water Use:

This category includes users who have access to communal (or collective) taps. This type of user has the same consumption rigidity as the previous group for the same reasons. Water consumption observed in the Steelpoort sub-basin, for this group, was slightly higher, then the previous group, at 0.8 m3/month/capita.

4.2.2.3 Indwelling Tap Water Use:

This group of domestic water users includes *urban* and *rural* categories. We assume in fact that users having access to indwelling water will have different consumptions depending on their socio-economic condition. According to the New Water Act (RSA, 1998), it would be important to study the impact of considering water as an economic good and the control the government could have on water demand by changing water prices. For that reason we introduced an economic demand function for indwelling water users who are considered to be able to change their water use as the price changes easier than the other groups. Still, assuming that there are different kinds of indwelling water users, we used two different functions for *urban* and *rural* users (Table 4.1). Recent studies in South Africa (Hassan and Farolfi, 2005) show that urban users' water demand has a higher elasticity to price than rural users water demand.

Table 4.1 Price/Demand functions for urban and rural water consumption/capita/month.

***Urban* user:**
$D = 8.89 - 0.38 \times P$
***Rural* user:**
$P < 0.24 \Rightarrow D = 1.29 - 1.21 \times P$
Else: $D = 1$
Where:
P: price of $1m^3$ of water
D: water demand (m^3/month/capita)

4.2.3 Villages' Water Uses

The *Village* agent, which is defined by the characteristics described above (Section 4.2.1), is the centre of decision for domestic uses. Therefore, according to the assumptions of the users of the model, its population, its '*urban or rural*' statement and its composition in terms of types of water users, will be initialised and then manipulated during simulations.

For each *Village* 'k' of the model a water demand is calculated each month from these characteristics according the following formula (Equation 4.1):

$$Vd_{kj} = P_k \cdot \frac{1}{10} \cdot \sum_{l=1}^{10} Ud_l(p, j) \qquad [4.1]$$

Where:

Vd_{kj} = *Village* 'k' water demand of month j

Pk = *Village* 'k' population

Udl (p, j) represents the function of water user type 'l' (as long as each *Village* contain 10 water user types), at a given the water demand of set price 'p' in a given month 'j'.

The next section presents *Village* placement and calibration.

4.2.4 Villages of KatAWARE

To place the *Villages* in the catchment, the Geographic Information System SA Explorer version 2.01 was used (Jhagoroo et al., 2005). Additional data on domestic water users were made available from previous work done on secondary data (Farolfi & Jacobs, 2005). In this data urban and rural population in the Kat River catchment and domestic water sources were estimated by *Ward*. The agents, *Villages*, were then calibrated using the characteristics of the *Ward* they belong to.

The population of a *Ward* was distributed over the *Ward's Villages* in the following way:

In a given *Ward*, the main residential centres (identified by the Rhodes University research team) share equitably 80% of the *Ward's* population and other, minor centres (identified by SA Explorer, Jhagoroo et al., 2005) share the remaining 20% of the population. When a *Ward* does not contain any important centre, the whole *Ward's* population is equitably shared among the places identified through SA Explorer (Jhagoroo et al., 2005). In one *Ward* no centre was identified, here a *Village* was added to represent the *Ward*'s population and domestic water users.

Wards assumed to be *urba*' are the Wards 17, 18, 21, 9 and 15 (Farolfi & Jacobs, 2005); all the *Villages* present in these *Wards* are described as *urba*'. All the others *Wards* are *rural*. The map in Figure 4.1 presents the *Wards* and the *Villages* as they are placed by SA Explorer.

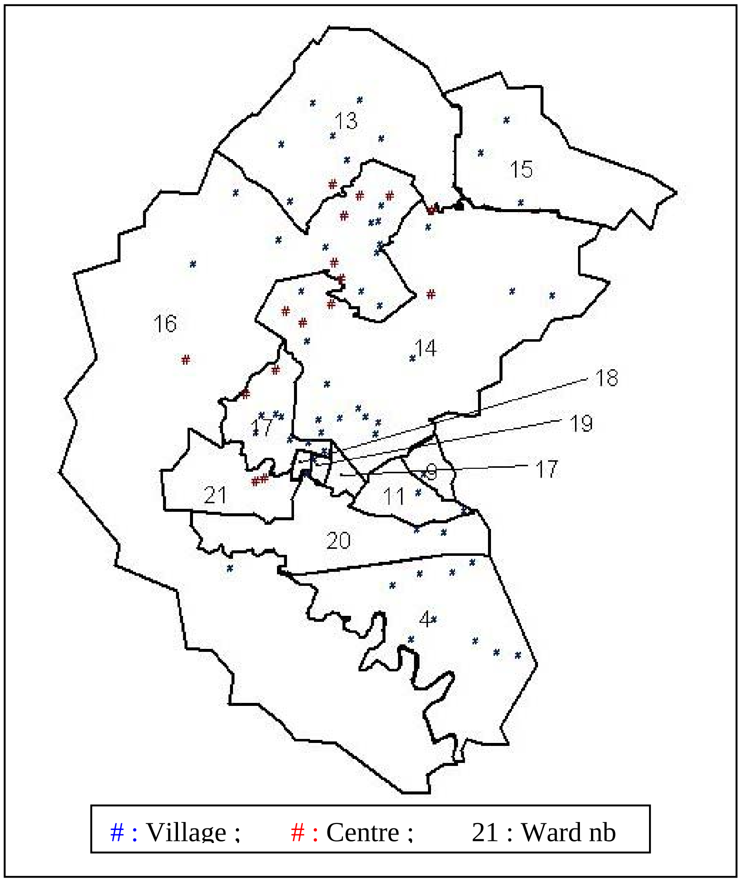

Figure 4.1 **Ward and Village location within the Kat River catchment (Research team and Jhagoroo et al., 2005)**

4.3 Irrigators

A *Farm* is made up of a set of C*ropping* S*ystems*, which correspond to the adoption of agricultural practices on a given surface, and a set of F*ixed Capitals*, which represent the most important structures required to support the use of a *Cropping System*. The *Farm* is only the production system; a *Farmer* makes the decisions, he/she can decide to commercialise his/her production in different *Markets*. The *Farmer* entity is the farming agent of the system; it will be described later.

The *Farm* entity is designed to allow a precise calculation of *Farm* budgets. *Cropping Systems* are the production units of the *Farm*. A C*ropping* S*ystem* is defined as a surface on which an ordered set of agricultural practices is implemented overtime. In the KatAWARE prototype the 'set of agricultural practices ordered in time' is referred to as a C*rop* D*escription*. For each time step these *crop descriptions* describe, on the one hand input needs (including water needs), labour force needs and F*ixed Capital* uses, and on the other hand yearly outputs.

All information available in the *Crop Descriptions* is relevant to one hectare. To consider C*ropping Systems*' evolution, all values are multiplied by the *Cropping Systems*' surfaces. According to the C*rop Descriptions* used, some costs such as fertilisers or pesticides costs are directly linked to each *Cropping System*, whereas other costs such as the cost for machineries that will be used on several *Cropping Systems* are linked to F*ixed Capitals*.

4.3.1 Crops described in the KatAWARE Prototype

On the basis of the primary and secondary data collected in the Kat River catchment (Farolfi and Jacobs, 2005; Farolfi and Abrams, 2005) it was chosen to use two different C*rop Descriptions*, which are considered to be representative of the crops farmed in the catchment. The first one is an annual crop (cabbage) that is largely produced in small-scale irrigation schemes and the second one is a perennial crop (citrus), which is the most important economic and water consuming activity in the Kat River catchment.

It is important to note that agricultural practices are defined on a yearly basis with the exception of water use that is modelled monthly. Therefore, a perennial C*rop Description* is divided into different *Periods* of various duration (number of years) describing a typical year of that specific *Period*. Obviously, annual *Crop Descriptions* are made-up of only a one-year duration *Period*.

4.3.1.1 Cabbage Crop Description

Cabbage is an annual crop; therefore, cabbage's C*rop Description* is made up of only one *Period* with a one-year duration. When the prototype was constructed, the only information source available on cabbage in the Kat River catchment was secondary data. More precise data i.e. budget data such as: inputs costs, labour force use and costs, production and market prices, come from a PhD study conducted in the area in 2000 (Ngqangweni, 2000). Table 4.2 presents the values used to build cabbage's C*rop Description* and *Markets* budget (Farolfi and Abrams, 2005).

Table 4.2 Budget for cabbage's *Crop Description*.

Budget for 1 Ha of cabbage				
Highlighted values used in cabbage *Crop Description* and *Markets*				
COSTS	**unit**	**quantity**	**R/unit**	**total**
Hired labour				
Seasonal employees	(h)	536	1.25	670
Labour costs				***670***
Variable costs				
Herbicide	(L)	2	361.3	722.6
Seedlings	(units)	25000	0.05	1250
Fertiliser	(ton)	0.5	1360	680
Fertiliser LAN	(ton)	0.5	1040	520
Pesticide	(ton)	0.02	31330	626.6
Pesticide	(L)	6	258.72	1552.32
Pockets	(units)	1675	0.85	1423.75
Land Preparation	(L of fuel)	30	6.5	195
Transport	(ha)	1	200	200
Water, repair, maintenance	(ha)	1	150	150
Variable Costs				***7320***
Total costs				**7990**
INCOME				
		quantity	Markets price	total
Production	(bags)	1675	6	10050
Total income				**10050**

No F*ixed Capital* is used in this C*rop Description*. In fact, the assumption that all *Fixed Capital* is provided by funding initiatives and, therefore, not paid directly by the farmers was made. In addition, secondary data are not precise enough to distinguish the different categories of costs for cabbage.

Data about irrigation requirements for this crop come from the South African software system Sapwat (Van Heerden, 2001); they are calibrated to the local situation using data from a meteorology station based in Fort Beaufort, the main town of the catchment. When irrigation is possible, 3 cycles of cabbage can be done during one year in the Kat River catchment. Cabbage's *Crop Description* considers one growth cycle a year from January to April. Irrigation requirements obtained from Sapwat are presented in Table 4.3 and Figure 4.2.

Table 4.3 Cabbage irrigation requirements from the Sapwat software system (m^3/month/ha).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
660	900	1190	370	0	0	0	0	0	0	0	0	3120

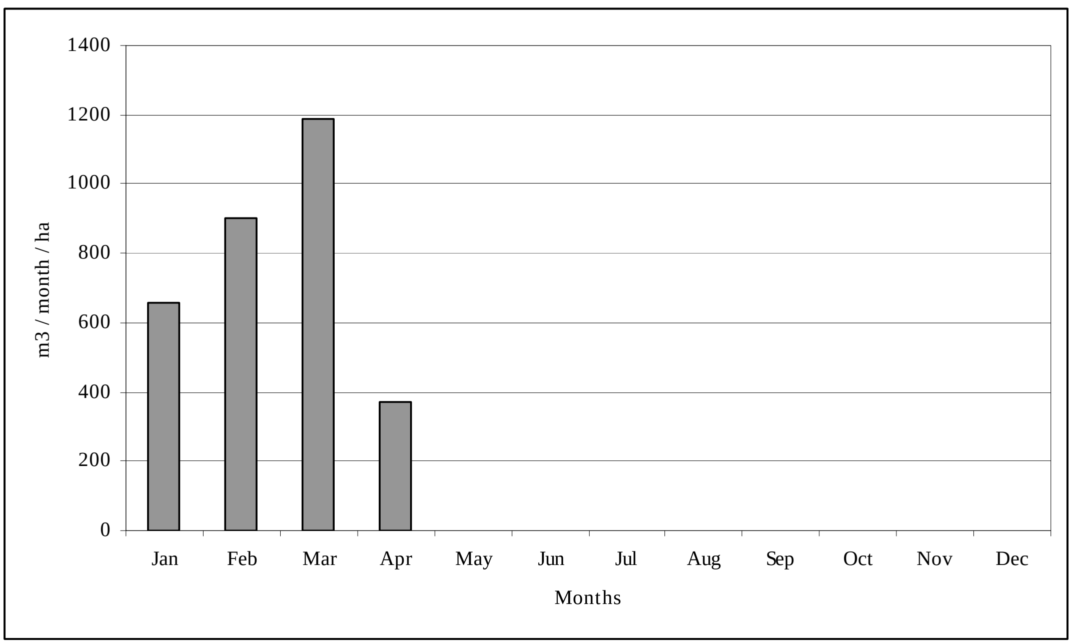

Figure 4.2 Monthly irrigation requirements of cabbage.

Cabbage's *Crop Description* is presented in Table 4.4. Notice that as mentioned before C*rop Descriptions* describe only production. Possible commercialisations of the crop outcomes are described in the form of *Markets*.

4.3.1.2 Cabbage Markets

If 2 formal *Markets* are defined (national and local), only one single set of marketing characteristics is allowed for cabbage, with both *Markets* having the same characteristics (price and Marketing costs). There are no marketing costs, and market price is set at 6 R/bag (A bag consists of 5 to 10 cabbages).

Table 4.4 *Crop Description* for cabbage utilised in the KatAWARE prototype.

Crop Description												
Crop Name:	Cabbage											
Planting cost:	0											
No. of Periods	1											
Period 1												
Duration:	1											
Monthly water needs	J	F	M	A	M	J	J	A	S	O	N	D
(m^3/monthly/ha):	660	900	1190	370	0	0	0	0	0	0	0	0
Hired Labour force (h):	Permanent	Seasonal	Casuals									
	0	536	0									
Variable costs:	R7 320											
Use of *Fixed Capital*:	None											
Output (bags of cabbage):	1675											

4.3.1.3 Citrus Crop Description

Citrus is a perennial crop, consequently its *crop description* was divided into two *Periods*. The first *Period* lasts four years and corresponds to the trees growing; the plants are assumed to be non productive during this *Period*. The second *Period* lasts 28 years and corresponds to the maturity of the trees.

The prototype version of the model assumes that the crop has the same water needs during the growing *Period* and the maturity *Period*. The same applies for the needs in terms of labour force, F*ixed Capital* and inputs. The only difference considered between the two *Periods* is production: there is no citrus production in *Period* one, while a constant annual yield (45 T/ ha) is harvested in *Period* 2.

Data on budget used to construct citrus *Crop Description* and citrus *Markets* come from local direct surveys with large-scale farmers (Farolfi and Abrams, 2005). The one-hectare citrus budget for productive *Period* is presented in Table 4.8.

Citrus water requirements were established by using local citrus farmers' irrigation pumps records. The yearly distribution of this amount of water comes from the Sapwat software system. As for cabbage, data from Sapwat were further calibrated to the local reality through data coming from the Fort Beaufort meteorological station. Irrigation requirements for the citrus C*rop Description* are presented in Table 4.5 and Figure 4.3.

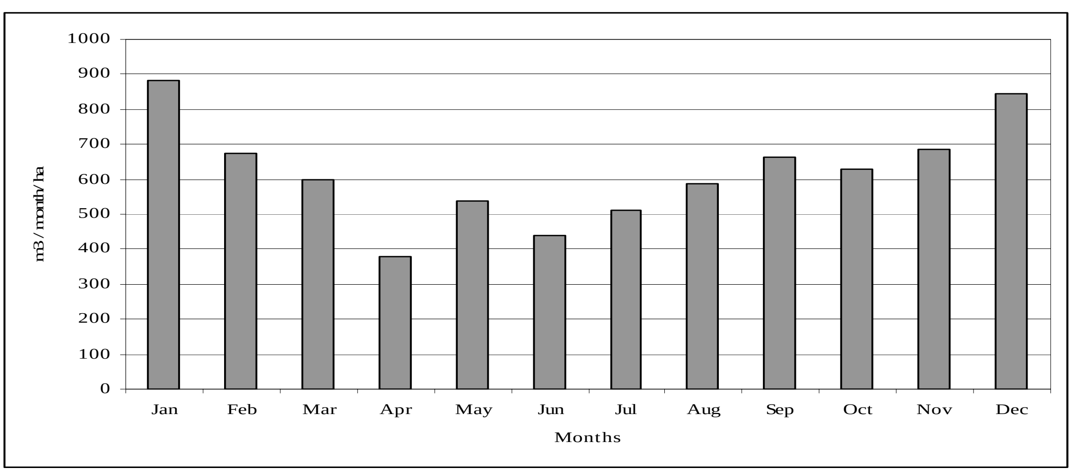

Figure 4.3 Monthly irrigation requirements (m^3/ha) for citrus production.

Table 4.5 Citrus *Crop Description*

Crop Description												
Crop type:	Citrus											
Planting cost (R):	31 500											
Number of Periods:	2											
Land costs (R/ha)	2000											
Period 1												
Duration:	4 years											
Monthly water needs (m^3/monthly/ha):	J	F	M	A	M	J	J	A	S	O	N	D
	884	674	599	380	537	438	513	587	661	628	686	843
Hired labour force:	Permanent		Seasonal		Casuals							
	330		560		585							
Variable costs (R):	11 500											
Fixed Capital:	Tractor		Boom sprayer									
	5%		3.3%									
Output (tons of citrus):	45											
Period 2												
Duration:	28 years											
Monthly water needs (m^3/monthly/ha):	J	F	M	A	M	J	J	A	S	O	N	D
	884	674	599	380	537	438	513	587	661	628	686	843
Hired labour force:	Permanent				Seasonal			Casuals				
	330				560			585				
Variable costs (R):	11 500											
Fixed Capital:	Tractor				Boom sprayer							
	5%				3.3%							
Output (tons of citrus):	45											

Table 4.6 **Budget for citrus *Crop Description*.**

Citrus budget for 1 ha of citrus				
Values used in determining the citrus *Crop Description* or *Markets* are highlighted.				
COSTS				
Installation costs				
	Amortisation	**Quantity/y**	**R/unit/y**	**Total/y**
Irrigation system	32 years	1.00	12000.00	375.00
Land preparation	32 years	1.00	7500.00	234.38
Plants	32 years	1.00	10000.00	312.50
Plantation	32 years	1.00	2000.00	62.50
Installation costs				***984.38***
Land				
Land renting		1.00		2000.00
Land cost				***2000.00***
Main machineries				
	Unit	**Quantity/y**	**R/unit/y**	**Total/y**
Tractor	% of availability	0.05	12000.00	600.00
Boom sprayer	% of availability	0.03	7000.00	231.00
Machinery costs				***831.00***
Labour costs				
Permanent	h	330.00	6.50	2145.00
Seasonal	h	360.00	7.00	2520.00
Casual	h	585.00	4.00	2340.00
Labour costs				***7005.00***
Variable costs				
Labour costs approximation				115.00
Pesticides				4000.00
Fertilisers				1700.00
Fuel and Oper. Costs				2600.00
Electricity				900.00
Repair/maintenance				1600.00
Small machinery				700.00
Variable costs				***11615.00***
Commercialisation costs				
International Markets	tons	31.50	1500.00	47250.00
Local Markets	tons	13.50	446.00	6021.00
Commercialisation costs				***53271.00***
Total costs				**75706.38**
INCOME				
		Quantity	**Market price**	**Total**
Production	tons	45.00		
Sells to:				
International Markets	tons	31.50	2750.00	86625.00
Local Markets	tons	13.50	833.00	11245.50
Total income				**97870.50**

4.3.1.4 Citrus Markets

There are two *Markets* defined for citrus commercialisation in the Kat River catchment; these are *international Markets* and *local Markets*. Both *Markets* have very different characteristics in terms of market prices and quality requirements (and consequent commercialisation costs) (Farolfi-Abrams, 2005). Citrus *Markets* are presented in Table 4.7.

Table 4.7 Citrus *Markets*

Citrus *Markets*:	*International Markets*	*National Markets*
Price (R/t):	2750	833
Marketing costs (R/t):	1500	446

4.3.1.5 Citrus Fixed Capitals

Whilst in the cabbage *Crop Description*, no *Fixed Capital* appears, because its costs are not covered by local *small-scale Farmers*, it does for the citrus' *Crop Description*. *Fixed Capitals* in the prototype include the following entities: machinery (tractors and boom sprayers); implantation structures (including irrigation systems, trees etc.); land (which is considered to be rented at a fixed price/ha). All F*ixed Capitals* are presented in Table 4.8.

Table 4.8 Citrus *Fixed Capitals*

Citrus *Fixed Capitals*	Tractor	Boom sprayer	Implantation structure	Land renting
Price/y:	12000 R	7000 R	984 R / ha	2000 R / ha
Duration (years):	15	15	32	32

4.3.2 Types of Farmers in the KatAWARE prototype

Following primary data sources describing the Kat River catchment (Farolfi and Abrams, 2005), three different types of *Farmers* populate the catchment: *large-scale Farmers, emerging Farmers,* and *small-scale Farmers* organised mainly in community-irrigation schemes. These types of *Farmers* and the explanation of such a farming situation in the catchment are described in a primary data report published by the research team of the project (Farolfi and Abrams, 2005).

4.3.2.1 Large-scale Farmers

Large-scale Farmers represent the citrus farmers of the middle and lower Kat River catchment (Figure 2.1); these are mainly white South Africans who own citrus farms larger than 20 ha. *Large-scale Farmers* export 70% of their production and pay in an amount of 0.05 R/m^3 for water. In the prototype the *Farmers* function through *Farms* composed of 8 C*ropping Systems* of identical surface growing citrus (citrus C*rop Description*, Table 4.6) and F*ixed Capitals* required by these C*ropping Systems*. The presence of 8 C*ropping* S*ystems* allows for a crop rotation that assures a continuous production. The difference of age between C*ropping* S*ystems* corresponds to 4 years. When the oldest is removed (age of 32 years) the youngest starts producing (age of 4 years) and a new one is planted (age of 0 year). This rotation is illustrated in Figure 4.4.

Every four years the oldest *Cropping System* is dug out and the one planted in the last *Period* becomes productive. A new one is planted during the next non-productive *Period*.

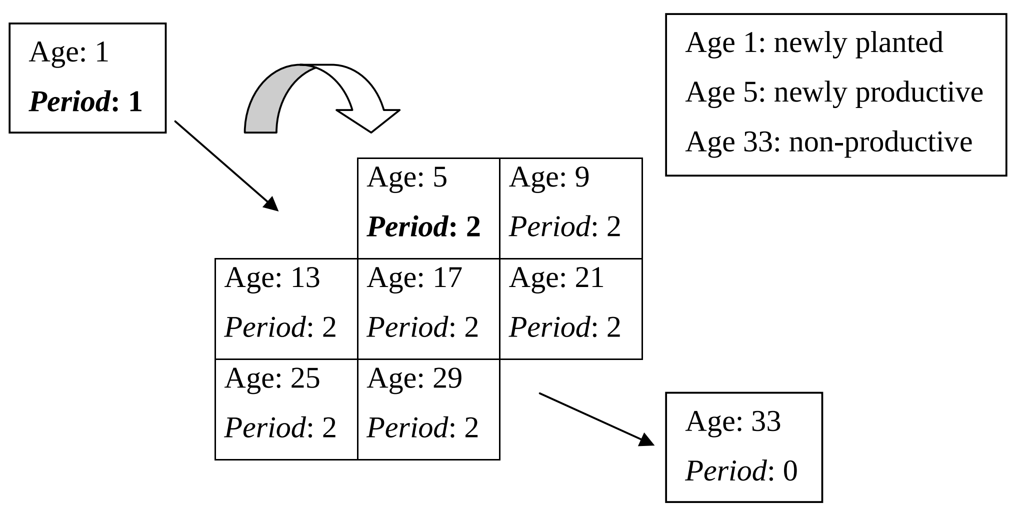

Figure 4.4 Rotation of citrus *Farm Cropping Systems*

4.3.2.2 Emerging Farmers

Emerging Farmers represent citrus farmers from the former homeland of Ciskei (upper and middle Kat River catchment, Figure 2.1) having usually less production means and smaller available surfaces. In the KatAWARE prototype *emerging Farmers* have the same characteristics as *large-scale Farmers* but they don't pay for water and have smaller citrus surfaces.

4.3.2.3 Small-scale Farmers

Small-scale Farmers represent community-irrigation schemes. Most of these schemes are in the upper Kat River catchment and only grow annual crops (Farolfi-Abrams, 2005). In the model an irrigation scheme is represented as one *Farm* managed by one *small-scale Farmer*. At the beginning of every simulation *small-scale Farms* are composed of one C*ropping System* of cabbage C*rop Description* with a total available surface of the whole irrigation scheme. During the simulations *small-scale Farmers* are able to install other C*ropping Systems* to their *Farms* according to different scenarios.

In the model each *Farmer* functions through a *Farm* and is linked to the relevant *Markets* where he sells his production. Whilst the marketing behaviour of cabbage producers is only oriented towards *local Markets*, citrus producers are defined by an *export rate*, which indicates what proportion of the production is exported. Similarly, the price of water is assumed to depend on the type of *Farmer* i.e. R0 price for cabbage producers (*small-scale Farmers*) and *emerging Farmers* (citrus) and 0.05 R/mc for *large-scale Farmers* (citrus).

4.3.3 *Farm* location in KatAWARE

Farm placement and calibration was done in respect to information obtained from direct surveys and secondary data (Farolfi and Abrams, 2005). Three small-scale community-irrigation schemes, of 30 ha each, were placed in the upper Kat River catchment each are represent the interests of s*mall-scale Farmers* in the model. 22 emerging *Farms*, producing citrus, were placed in the southern part of the middle Kat River. They have a total surface area of about 400ha (18 ha each) and are managed by *emerging Farmers*. Citrus *Farms* in the lower Kat River are all considered to be involved in large-scale commercial citrus production. 11 l*arges-scale Farmers* were placed in this part of the Kat River catchment and cover a total surface area of 870 ha. Table 4.9 and Figure 4.6 summarise *Farms'* position, type, and surface in the KatAWARE prototype.

Table 4.9 Summary of farming in the KatAWARE prototype

Farmers	***Farms'* surfaces**	**Position**	**Crops**	**Water payment**
3 smallholder	30 ha	Q94B & Q94C	Cabbage	No
22 emerging	18 ha	Q94E	Citrus	No
1 large-scale	300 ha	Q94F	Citrus	Yes
5 large-scale	24 ha	Q94F	Citrus	Yes
5 large-scale	90 ha	Q94F	Citrus	Yes

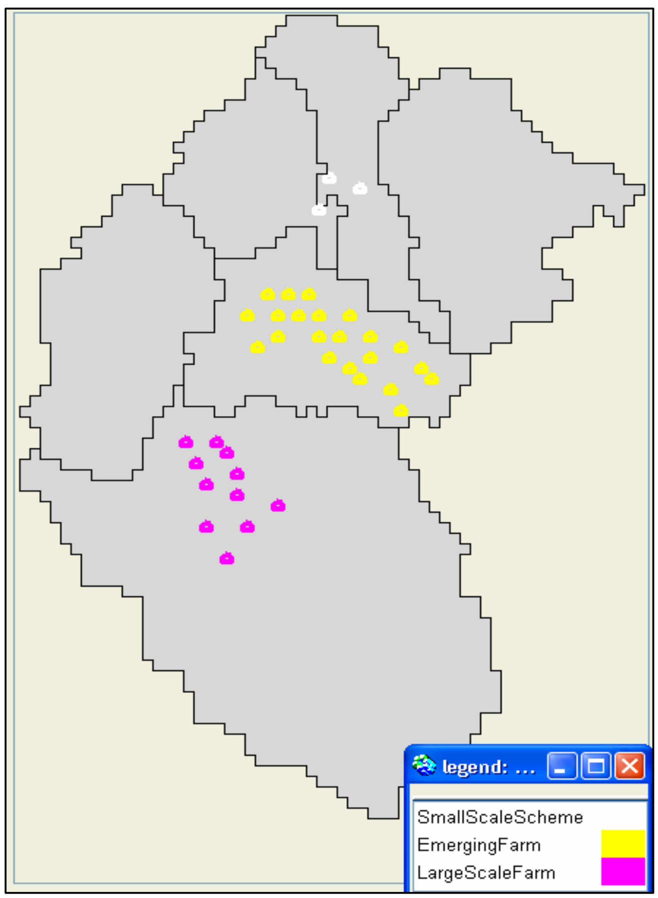

Figure 4.6 *Farm* locations in the KatAWARE prototype model

5. EVOLUTION RULES AND SCENARIOS

This chapter focuses on the sequence of activities that occurs with each simulation's time step, enabling the reader to distinguish the actions of each entity (described in Section 2.1).

As previously mentioned there are two time steps in the KatAWARE prototype: a monthly time step for hydrological dynamics and a yearly time step for socio-economic evolutions. Different scenarios were defined to represent socio-economic evolutions. These scenarios were constructed on the basis of interviews and conversation with local stakeholders.

5.1 Monthly Time Step: Hydrological Dynamics

Every *month* each entity performs activities linked to the hydrology as it is described in the UML sequence diagram in Figure 5.1. It is worthwhile noticing that monthly activities are performed S*ub-catchment* by S*ub-catchment*, from upstream to downstream.

Upstream Sub-catchments supply *downstream Sub-catchments* in a semi cumulative manner. Each *downstream Sub-catchment* has a yield relative to its *monthly self yields* and its own *water consumption* and that of the *upstream Sub-catchments*, which is calculated relative to the entity (*Farms* and *Villages*) activity in each *Sub-catchment*. This yield represents the *water availability* in each *Sub-catchment*. The monthly activities have the same definitions in all scenarios.

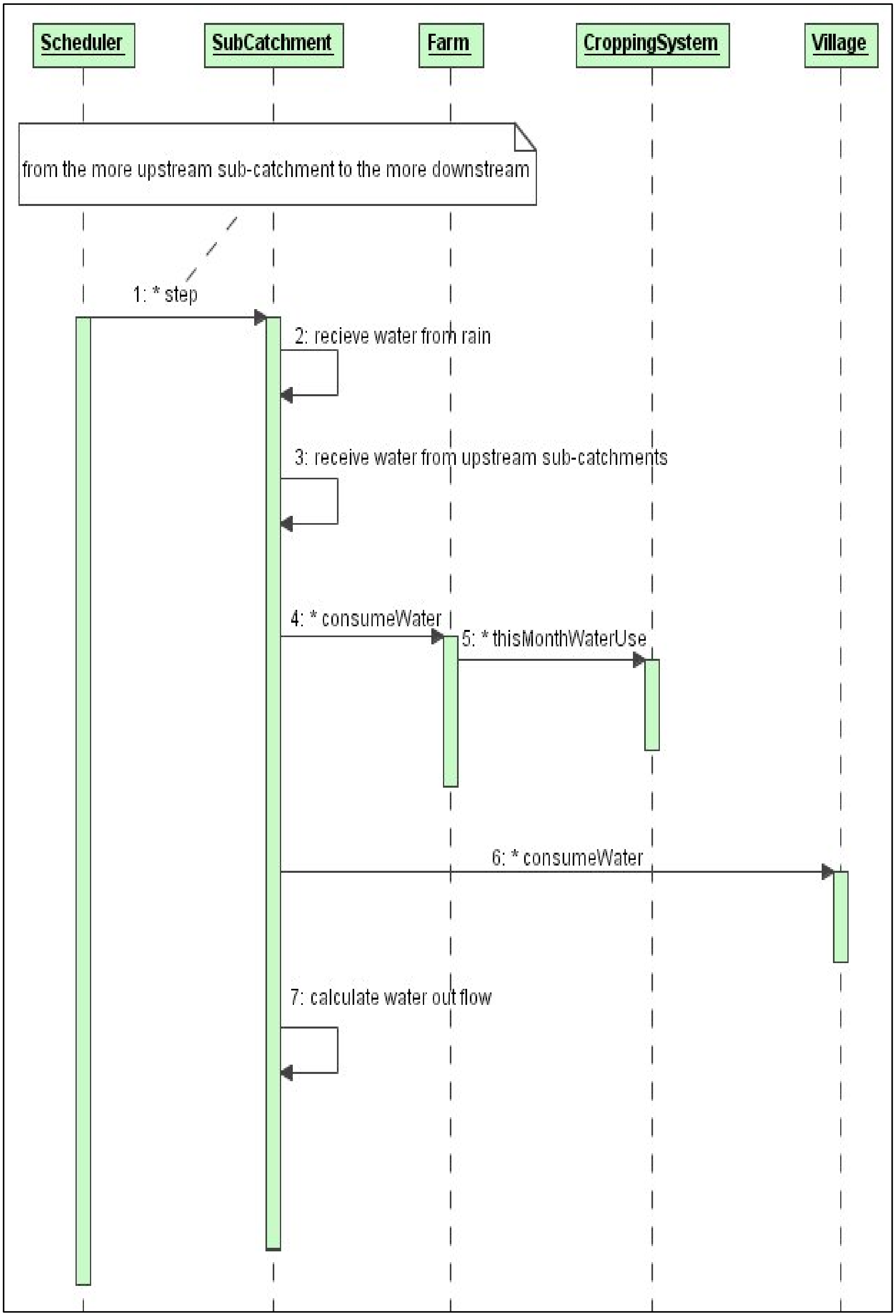

Figure 5.1 UML sequence diagram in the KatAWARE prototype: Monthly Step

5.2 Yearly Time Step: Socio-economic Evolutions

Each *year* entities perform activities linked to their socio-economic situations as described in the UML sequence diagram Figure 5.2.

Agents (*Farmer* or *Village*) are provided with the opportunity to change basic operating characteristics each year. For a *Village* these characteristics include its composition in terms of types of *water uses* or its *population;* or a *Farmer* has the ability to change their *Farm's Cropping Systems* with each simulation step.

It can be observed in the sequence diagram (Figure 5.2) that *Villages* 'evolves' in one simulation step. This 'evolve' activity can be defined differently according to scenarios. The *Farmer's* simulation step is more complicated, because it occurs relative to the *Farm's* yearly activities which include: C*ropping* S*ystems'* evolution (which involves an age change); *Farm* production; selling of the production on *Markets*; and the calculation of socio-economic outputs (labour, costs, and incomes). It also incorporates a decision step - 'make decision' - during which the Farmer can add a new *Cropping System* to their *Farm*. This last activity is defined differently according to the different scenarios.

Some of the scenarios implemented in the KatAWARE prototype are described in the following paragraphs.

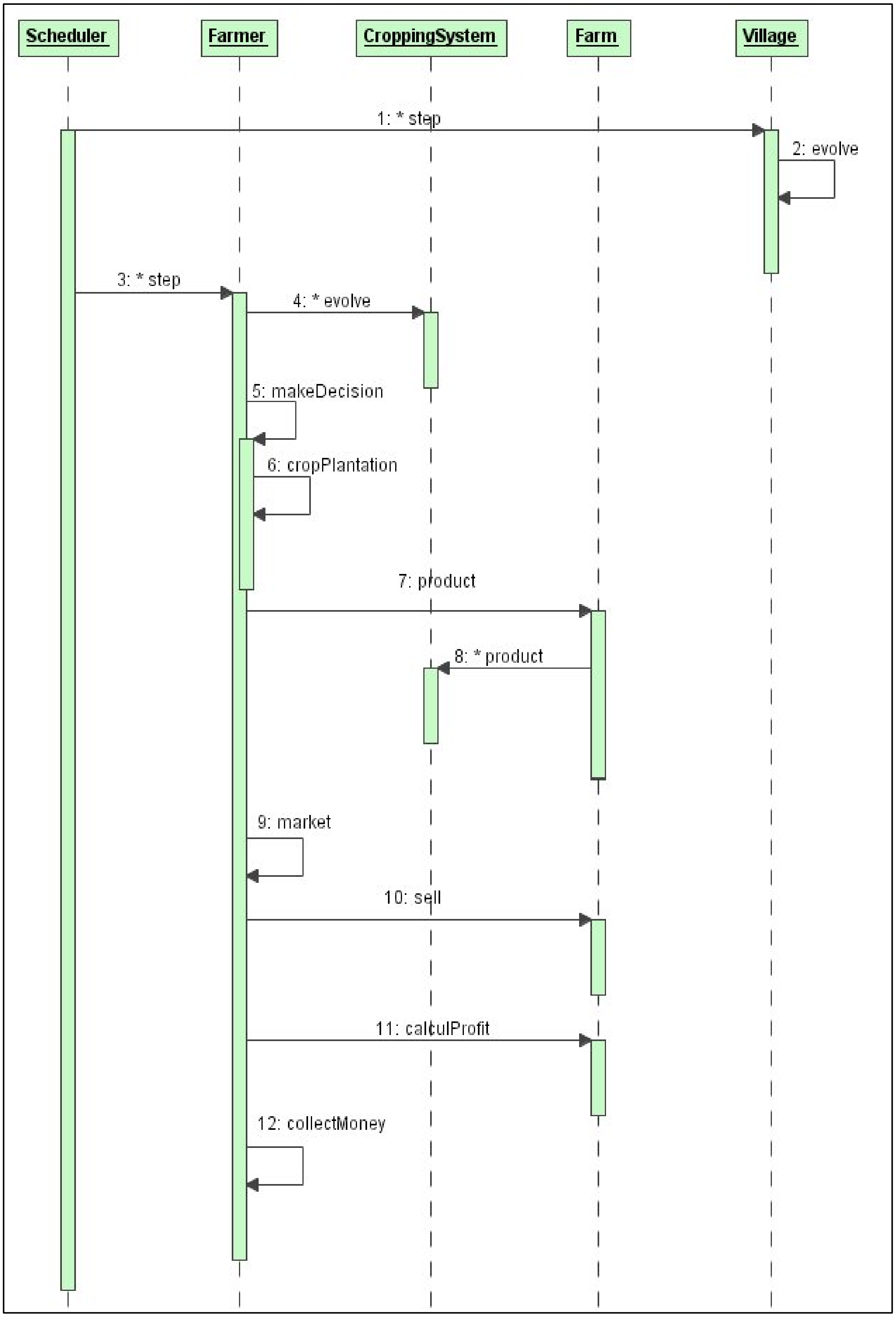

Figure 5.2 **UML sequence diagram in the KatAWARE prototype: Yearly step**

5.3 Scenarios

5.3.1 Baseline Scenario

The ‘evolve’ step for *Villages* (Figure 5.2) consists of no change in associated attributes or characteristics. In other words *Villages* remain the same year after year.

The ‘make decision’ step for *Farmers* consists of replacing the previous C*ropping Systems,* with a new one. This can either be the same system again or the implementation of the alternative i.e cabbage or citrus. The available surface used remains constant throughout the simulation. Cabbage C*ropping* S*ystems* are replaced every year and Citrus C*ropping Systems* every 32 years.

5.3.2 *Domestic Water Users Evolution Scenario*

The ‘evolve’ step for *Villages* involves progressively replacing all *river water uses* by *collective tap water uses* during the first five years of the simulation, and then all *collective tap water uses* with *indwelling tap water uses* from the fifth year to the tenth year. *Farmer* behaviour is the same as in the baseline scenario (Section 5.2.1).

One should notice that this scenario is very ‘optimistic’ in that it simulates the provision of *indwelling tap water* to all rural domestic users in a very poor area characterised by one of the lowest rate of water services at present. Nevertheless, it is important to take into account, for the scenario’s simulation, that there will be increase of domestic-indwelling consumption in the catchment. This consideration incorporates the common desire by all rural stakeholders in the Kat River catchment to have easy access to water supply.

5.3.3 Small-scale Farmers Evolution Scenario

Village behaviour is the same as in the baseline scenario (Section 5.2.1).

The 'make decision' step for *small-scale Farmers* involves regularly replacing their cabbage C*ropping Systems* by citrus C*ropping System.* Through this action, although they will still have *Farms* that have the same surface area, they will by the tenth year be entirely composed of citrus *Cropping Systems*. Other *Farmer* behaviour is the same as in the baseline scenario.

This scenario reflects the willingness of some *small-scale Farmers* to move towards citrus production and at the same time the fact that commercial citrus corporations in the middle Kat River (Riverside and Katco) have the capacity to pack more citrus in their package sheds.

5.3.4 Farming Evolution Scenario

Village behaviour is the same as in the baseline scenario.

Small-scale Farmer behaviour is the same as described in Section 5.2.3.

The 'make decision' step for other *Farmers* involves the replacement of old C*ropping Systems* with new ones each year over a ten year cycle. The new C*ropping System* is a citrus C*ropping System* and its surface is equal to 12.23 % of the initial *Farm* surface. This coefficient has been calculated in such a way that the total surface reaches 2130 ha at the end of the simulation. This total surface represents the total surface assumed to be potentially cultivated (and therefore scheduled for irrigation) in the Kat River catchment, according to direct surveys conducted with local large-scale farmers.

This scenario is extreme but doesn't seem un-realistic according to the available data. The irrigated surface planned to be supplied by the Kat River Dam corresponds to a 'Scheduled area' of about 1500 ha and is suitable for citrus, whilst more than 400 ha are already irrigated from farm dams and weirs outside that 'Scheduled area'.

5.3.5 Combined Evolution Scenario

In this scenario *Village* behaviour is the same as in the Domestic Evolution Scenario (Section 5.2.2) and *Farmer* behaviour is the same as in the Farming Evolution Scenario (Section 5.2.4).

6. OUTPUTS

As an example of the KatAWARE prototype outputs this chapter illustrates and comments on the scenario ‘combined evolution’ (Section 5.2.5) run over 10 years.

6.1 Socio-economic Dynamics and their Impact on the Water Demand

As said previously water users (*Villages* and *Farmers*) evolve each year according to the considered scenario. Here the evolution of an *urban Village* and of a s*mall-scale Farm* during the chosen simulation is illustrated.

6.1.1 Villages Evolution

Figures 6.1 and 6.2 present the evolution of a *Village's* composition in terms of water sources and water demand respectively. Issues of equity in domestic water provision and its (limited) impact on the total water demand in the catchment can be discussed amongst stakeholders relative to these figures.

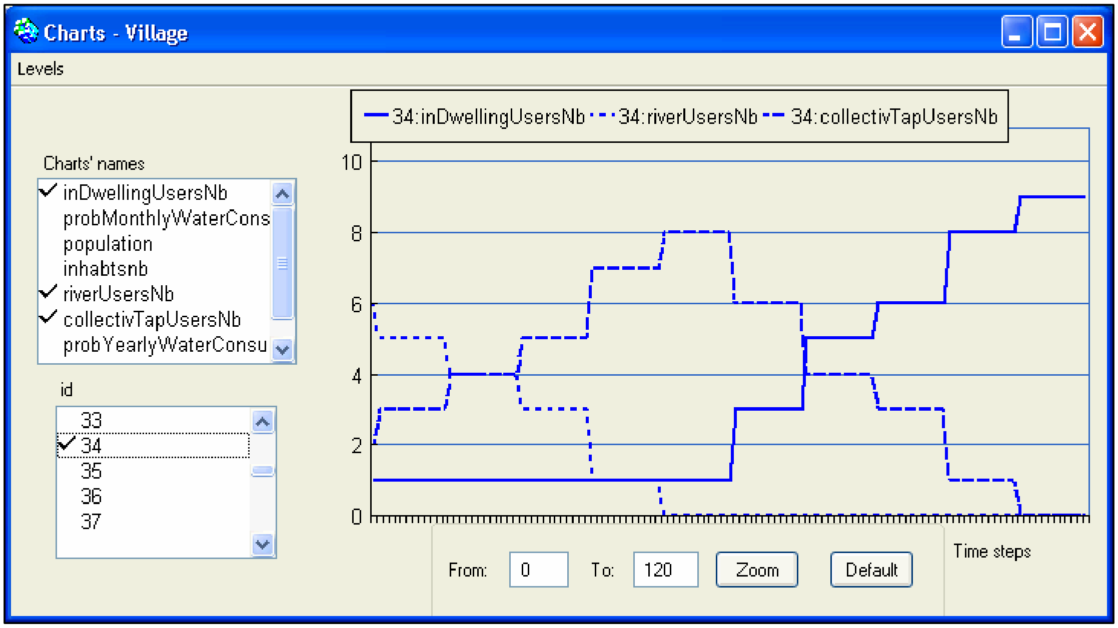

Figure 6.1 Changes in water sources in a *Village* (No. of households having access to the three different types of sources) over the simulation time step.

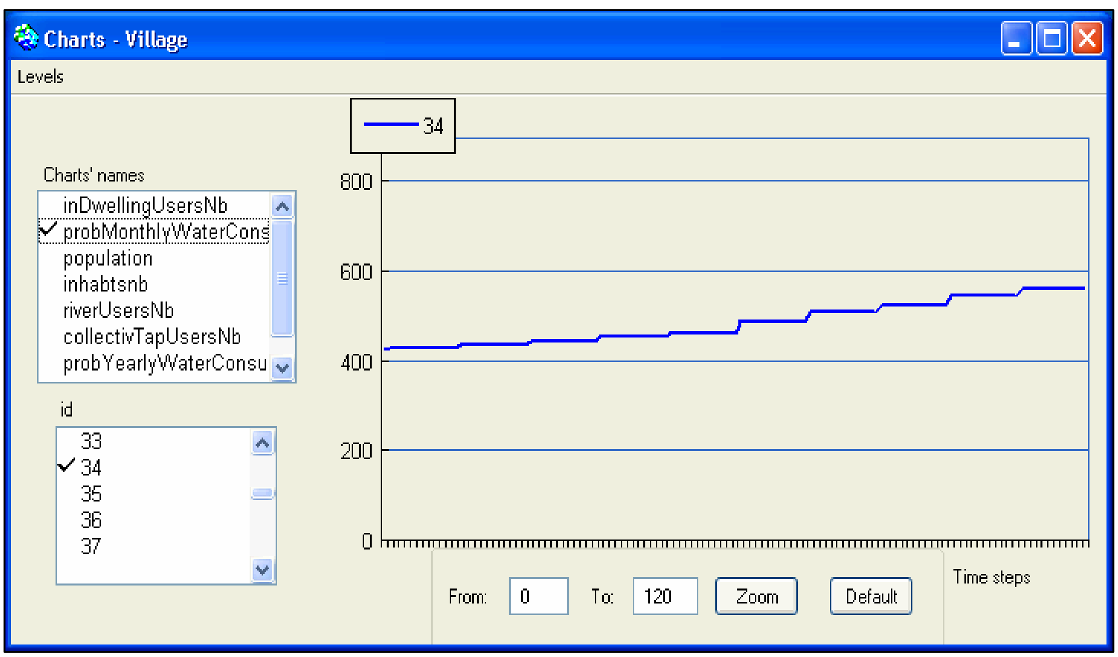

Figure 6.2 Village monthly water demand (m^3) over simulated time step

6.1.2 Small-Holder Farm Evolution

The evolution assumes, within the scenarios, that the *Farmers'* will decide to plant new crops i.e. from cabbage to citrus. In the model it corresponds to the installation of new C*ropping Systems* to their *Farms*. As seen previously, *Farm's* composition (in terms of C*ropping Systems*) corresponds to all its production characteristics, including water demand (Figure 6.3 and 6.4).

Different kinds of issues can be observed from these outputs:

- Social ones: types and number of jobs created change according to the farming choices (Figure 6.5).
- Economic ones: it can be observed that citrus implantation requires an investment that cabbage producers cannot afford (Figure 6.6).
- Environmental ones: working at the S*ub-catchment* scale enables the discussion concerning water availability and environmental requirements to be discussed as explained in the next section.

6.2 Consequences on Water Stresses observed Monthly

The model calculates monthly water demand and water supply in each S*ub-catchment* according to the given scenario. Figures 6.7 and 6.8 present water demand and water supply in S*ub-catchment Q94F*. From these figures it can be observed that the water demand in Q94F, in the lower Kat River catchment (Figure 2.1) is higher then water supply during certain months. This indicates a localised and temporally identified stress on the resource (Figure 6.7).

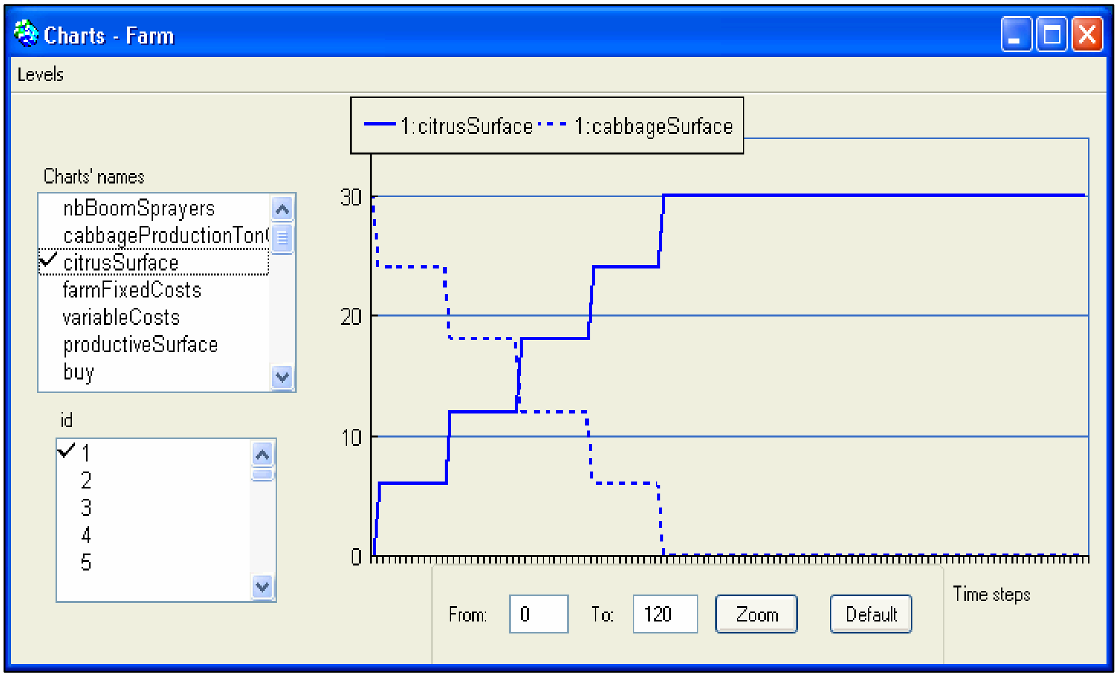

Figure 6.3 **Changes to *small-scale Farmer* irrigation scheme demand between cabbage and citrus cultivation**

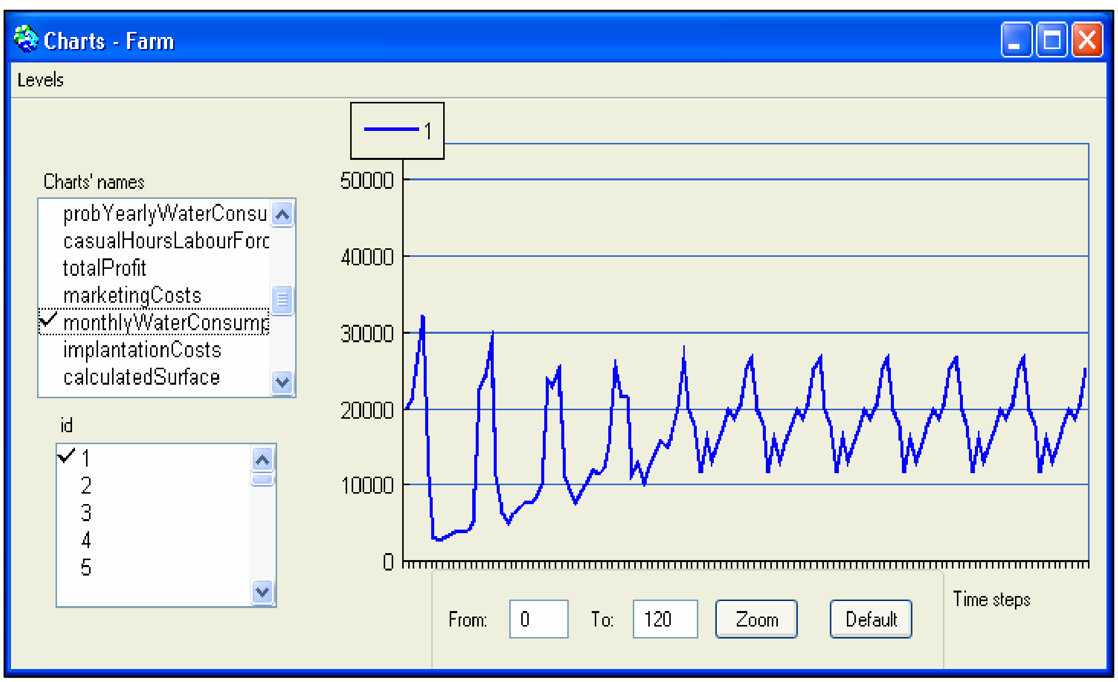

Figure 6.4 ***Small-scale Farmer* irrigation scheme: annual water demand (m^3)**

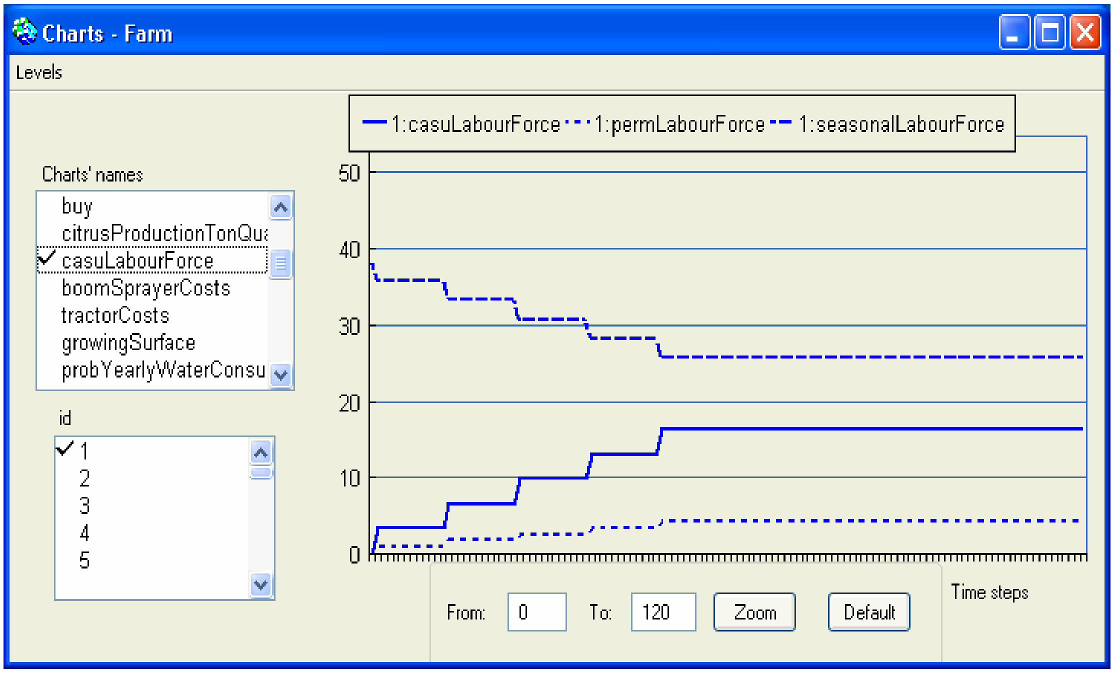

Figure 6.5 ***Small-scale Farmer*** **irrigation scheme: Labour force employed**

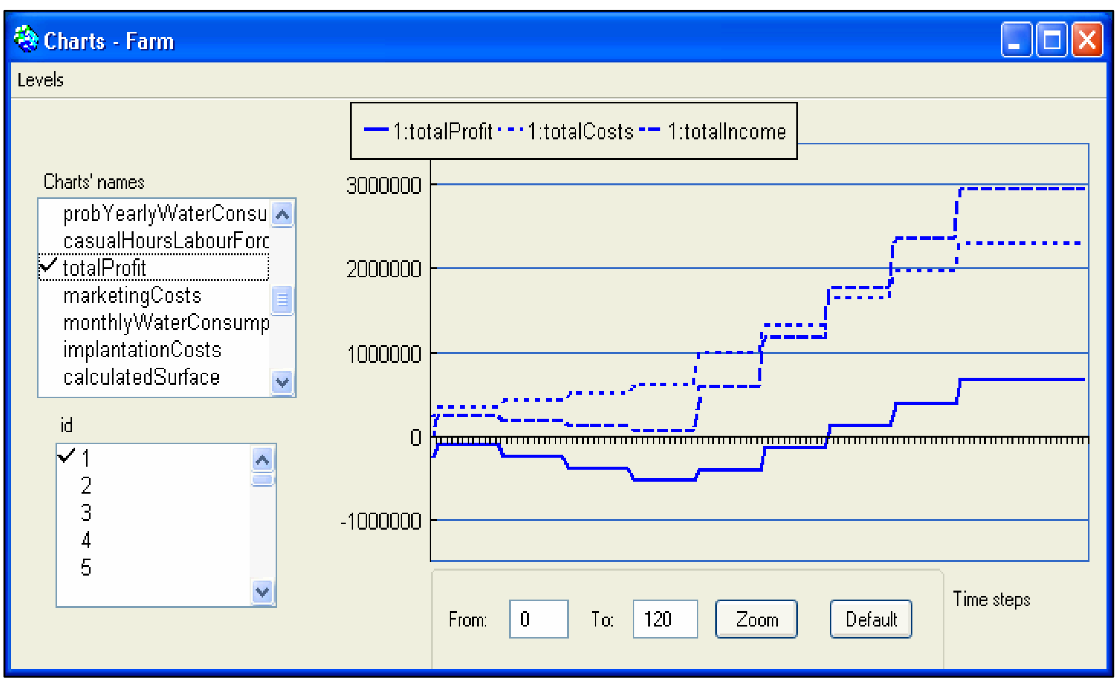

Figure 6.6 ***Small-scale Farmer*** **irrigation scheme: Annual costs, income and profit (R)**

This is an environmental issue (in respect to the Reserve) that can be discussed with the stakeholders. In this specific case a stress appears because at the end of the simulation, citrus farming has increased. Therefore, during the months when water demand for citrus is higher, a high catchment demand upstream of Q94F has resulted in a lower water supply in the *Sub-catchment*. It is worthwhile noticing that this observation is also due to the assumption made that the Kat River Dam releases a constant amount of water every month (i.e. there is no real control on the Dam releases).

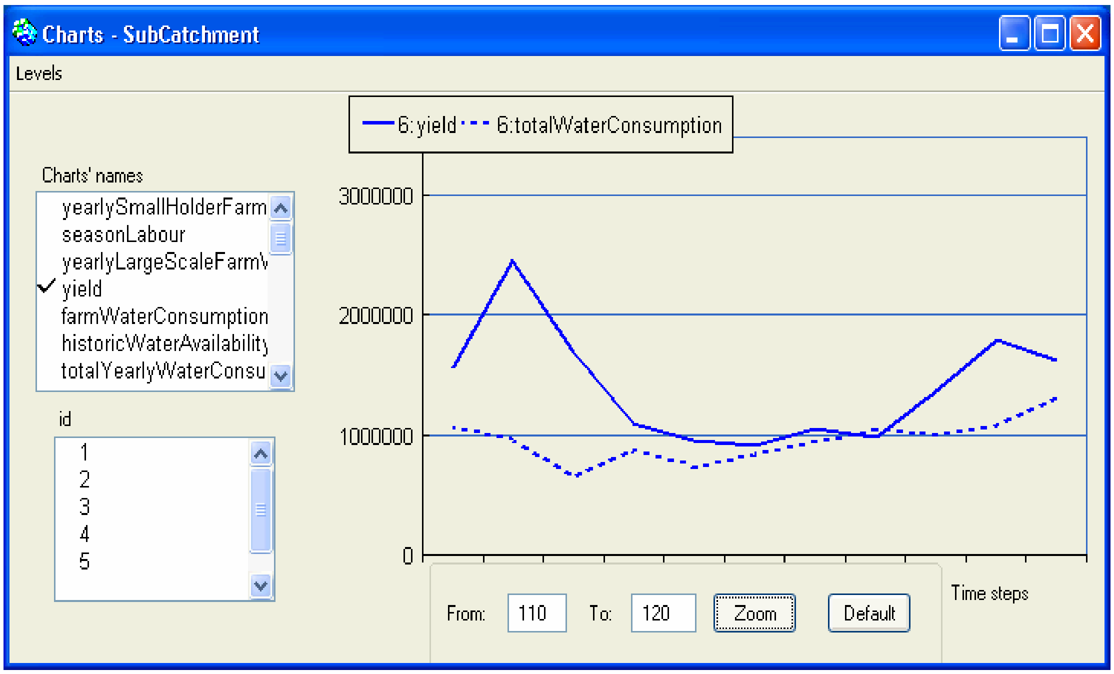

Figure 6.7 ***Sub-catchment* Q94F: water demand and water supply at year 10 (January to December) (m^3)**

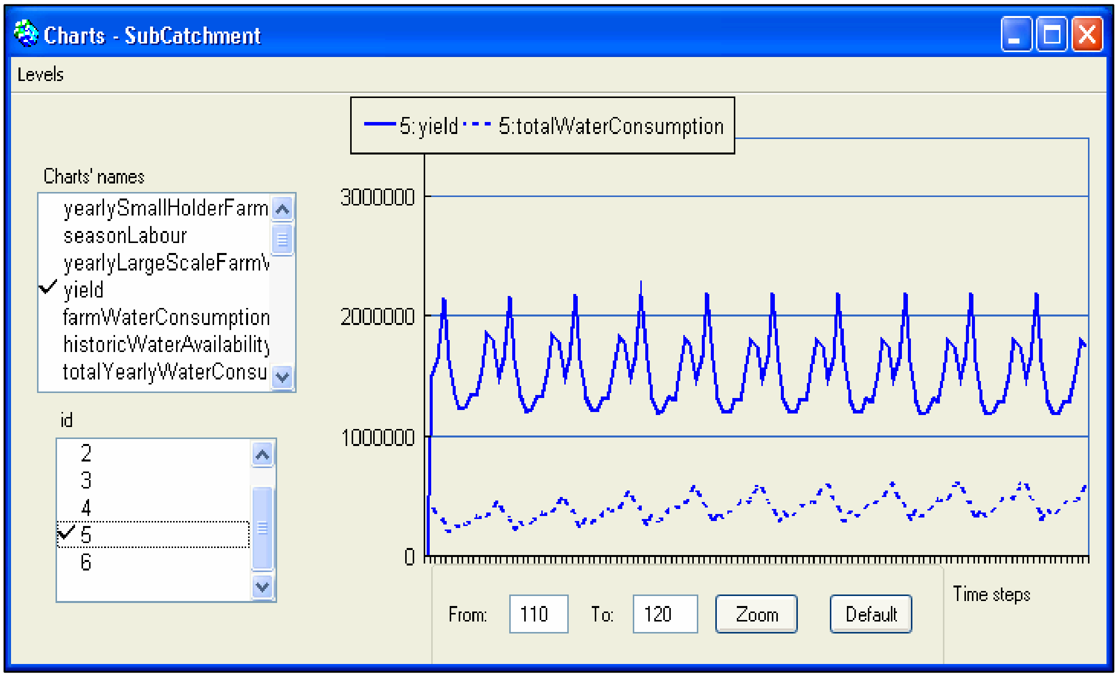

Figure 6.8 ***Sub-catchment*** **Q94F: water demand and water supply over the ten-year simulation (m^3)**

7. MODEL'S USER INTERFACE

According to the adopted Companion Modelling approach, it is crucial to have an effective support (graphical interface) allowing for discussion with and among relative stakeholder representatives, in our case the Kat River Water Users Association (KRWUA), on the model outcomes. Consequently special care was given to the choice of different ways of representing the model's outputs.

7.1 Spatial Simulation Interface

To facilitate stakeholders' comprehension of the spatial dynamics represented in the prototype it was decided to use a map of the catchment with different colours representing the state of water demand and water supply at a time't'. The change in relationship between water demand and water supply in a certain zone of the catchment determines a change of colour. This way of representing spatial dynamics in the catchment has proved to be successful in the workshops held to date; especially with respect to the less advantaged stakeholders whose educational level does not allow for easy comprehension of more complex representations i.e. like tables and graphs. Two interfaces used during the presentation of the model to the KRWUA (Burt et al., 2005) are presented in Figures 7.1 and 7.2.

The first one (Figure 7.1) allows for the visualisation of water demand month after month relative to location in the catchment. To each S*ub-catchment*[4] is attributed a colour (green) depending on its water demand it will become darker or lighter (darker with increase in demand). To allow the participant to follow the change in simulation colour representations, the various simulation time steps (month and year) appear on the screen. Because of its simplicity this interface proved useful to introduce some of the concepts of the model (i.e. basic dynamics of the model, representation by *Sub-catchments*, etc.).

[4] As previously indicated there are three different spatial divisions in the KatAWARE prototype: S*ub-catchments, Wards and Voting Areas*. But only the S*ub-catchment* division allows a representation of both the water supply and the water demand.

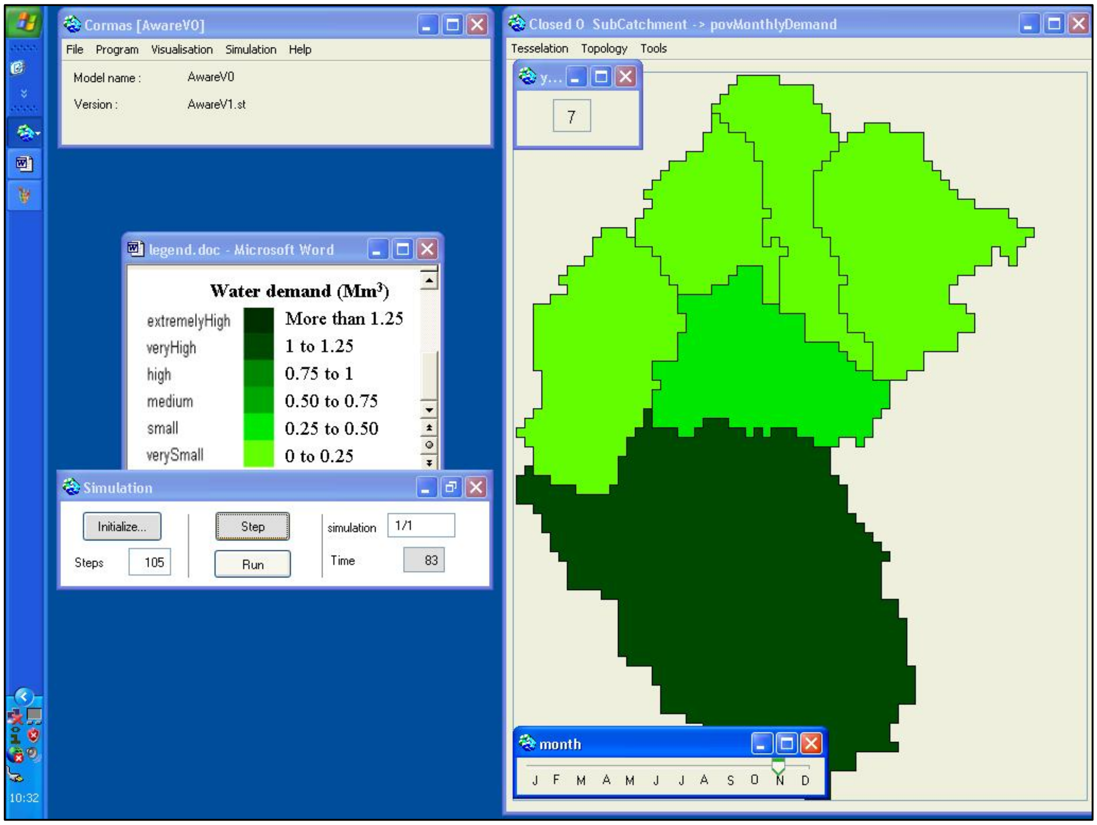

Figure 7.1 **Simulation interface: visualisation of water demand in the Kat River catchment (year 7; November)**

The second graphical interface (Figure 7.2) combines water demand and supply in the catchment. This visualisation highlights the stresses observed. In this representation the colour attributed to each S*ub-catchment* corresponds to the water demand/water supply ratio (blue for no stress, red for intermediate stress, and black for highly stressed sub catchments). Because this is a more complex notion to apprehend, this representation is also supported by three pairs of histograms corresponding to three given S*ub-catchments* (Q94B, Q94D & Q94F). In each set of histograms the left hand side histogram represents the water supply and the right hand side one the water demand, both in million cubic meters. When water demand equals the supply, the S*ub-catchment* appears in ‘Black’, which corresponds to a ‘total consumption’. The other series of histograms that appears in this interface represent the amount of water flowing out of the catchment each month. During the first workshop of presentation and discussion of the KatAWARE prototype, this interface, more complex than the first one, was nevertheless well understood and discussed by the stakeholders that were being introduced to the model.

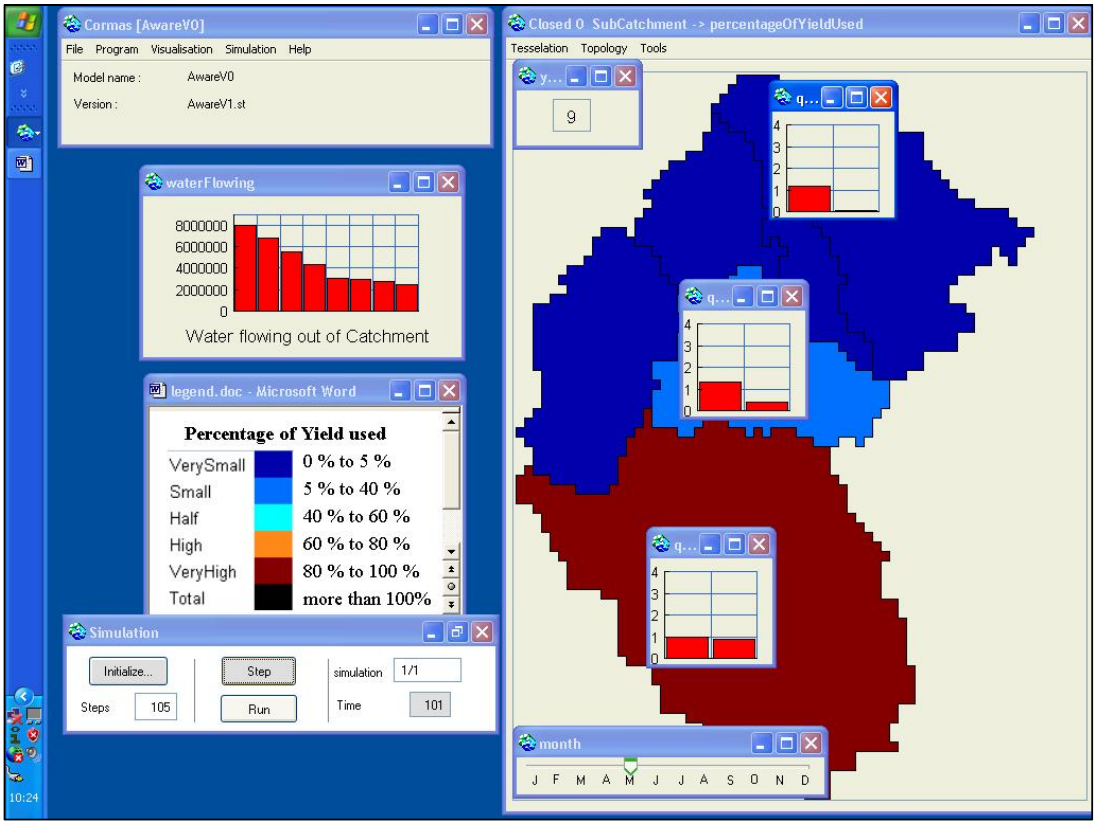

Figure 7.2 **Simulation interface: visualisation of the water demand/water supply ratio in the Kat River catchment (year 9; May)**

7.2 Charts

When the simulation is stopped, it is possible to follow the historical trends of all variables in the model through graphs presenting monthly simulated values for the various variables. These visualisations further inform the stakeholders and allow visualisation of almost all information in the model. These charts summarise the phenomena observed during a simulation and are of great importance for supporting discussions on 'what happens if' variables in the model change and why. Negotiation and decision support can be greatly helped through these visualisations.

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