NeWater

CATCHMENT DOMAIN MODEL

Part B. Focus on the Guadiana basin

Modelling the diversity of buffering capacity on semi-arid catchments

Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty

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Policy Summary

This document is the second part of the deliverable 1.5.3 of Work package 1.5 dedicated to the Guadiana basin. The first part is dedicated to Rhine basin.

The Guadiana basin is under a semi-arid climate typical of the central Iberic peninsula. As a result modelling buffering capacity and more generally water quantity storages is a complex task as several terms of the water balance become equivalent (Sutcliffe, 2004):

- Evapotranspiration is high with hot temperatures,
- Rainfall is limited due to the semi-arid meteorological conditions,
- Water withdrawals are important due to the over-exploitation of surface and groundwater resources mainly for irrigation purposes.

Hence, understanding and modelling buffering capacity cannot rely on a single approach but has to explore various methods to avoid simplistic vision of the water system. After defining the objective of buffering capacity management objectives in chapter 2, two different perceptions of buffering capacity have been highlighted for two different parts of the basin:

- In the Upper part, buffering capacity is oriented towards the long-term management of groundwater resources. Here buffering capacity is defined as the *number of years required to obtain a recovery of wetlands under various management actions and economic scenarious*. These aspects are presented in chapter 3.
- In the Lower part, the same concept is adapted to short or medium term management of surface water reservoirs. Here buffering capacity is *defined each month as the reservoir filling deficit*. This deficit is measured with a synthetic indicator comparable to the Palmer Drought Severity Index (see Pa lmer, 1965). These aspects are presented in chapter 4.

Both approaches are supported by the construction of catchment domain models based on two different paradigms:

- For the Upper Guadiana, a knowledge based model is proposed (Bayesian belief network),
- For the Lower Guadiana (and more precisely for the Caia reservoir system) a deterministic hydrologic model has been built based on the GR2M rainfall runoff model.

The first model is still in a development phase as the interaction with stakeholders just started. The second model provides satisfactory results considering its extreme parsimony.

These tools allow to go a step further in the understanding of buffering capacity management by providing means to calculate the buffering capacity criteria defined previously. The next step is to finalize this calculation through interaction with stakeholders.

Policy recommendations

This document does not contain any prospective vision on water management in the selected area. The aim is only to build realistic models based on local knowledge and improve buffering capacity understanding. The use of these models to participate in the building of water management scenarios will be presented in deliverables D 1.5.6: "Methods to use the domain models in an adaptive management perspective".

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1 Introduction

This document is the second part of the deliverable 1.5.3 of Work package 1.5 dedicated to the Guadiana basin. The first part is dedicated to the Rhine basin.

During the year 2006 and more precisely at the NeWater General assembly in Hortobagy (Hungaria), Guadiana case study stakeholders have shown great interest in improving buffering capacity management at the basin scale.

Guadiana basin is under a semi-arid climate typical of the central Iberic peninsula. As a result modelling buffering capacity and more generally water quantity storages is a complex task as several terms of the water balance become equivalent (Sutcliffe, 2004):

- Evapotranspiration is high with hot temperatures,
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- Water withdrawals are important due to the over-exploitation of surface and groundwater resources mainly for irrigation purposes.

Hence, understanding and modelling buffering capacity cannot rely on a single approach but has to explore various methods to avoid simplistic vision of the water system.

After defining the objective of buffering capacity management objectives in chapter 2, this report presents two different perceptions of buffering capacity modelling:

- In chapter 3, probabilistic graphical models known as "Bayesian belief networks" are used to analyse groundwater management in the upper part of the Guadiana basin ("Mancha Occidental").
- In chapter 4, deterministic hydrological models are applied to analyse the management of a reservoir (Caia reservoir) in the downstream part of the basin.

This document does not contain any prospective vision on water management in the selected area. The aim is only to build realistic models based on local knowledge and improve buffering capacity understanding. The use of these models to participate in the building of water management scenarios will be presented in deliverables D 1.5.6: "Methods to use the domain models in an adaptive management perspective".

2 Managing buffering capacity in semi-arid basins

Managing buffering capacity (BC) requires first to define it properly, then to measure it on clear scientific basis and finally to propose strategies to optimise its management.

As mentioned in the introduction, this report will concentrate on the first two aspects, the third one (new strategies for water management) being covered in another deliverable of work package 1.5 (Deliverable 1.5.6).

The definition of buffering capacity is presented in section 2.3 with buffering capacity criteria.

To apply these criteria to the Guadiana basin, catchment domain models are developed in sections 3 and 4. The final calculation is not presented in this report as it requires interaction with stakeholder.

Hence this report only aims to develop tools and methodology to improve the management of buffering capacity.

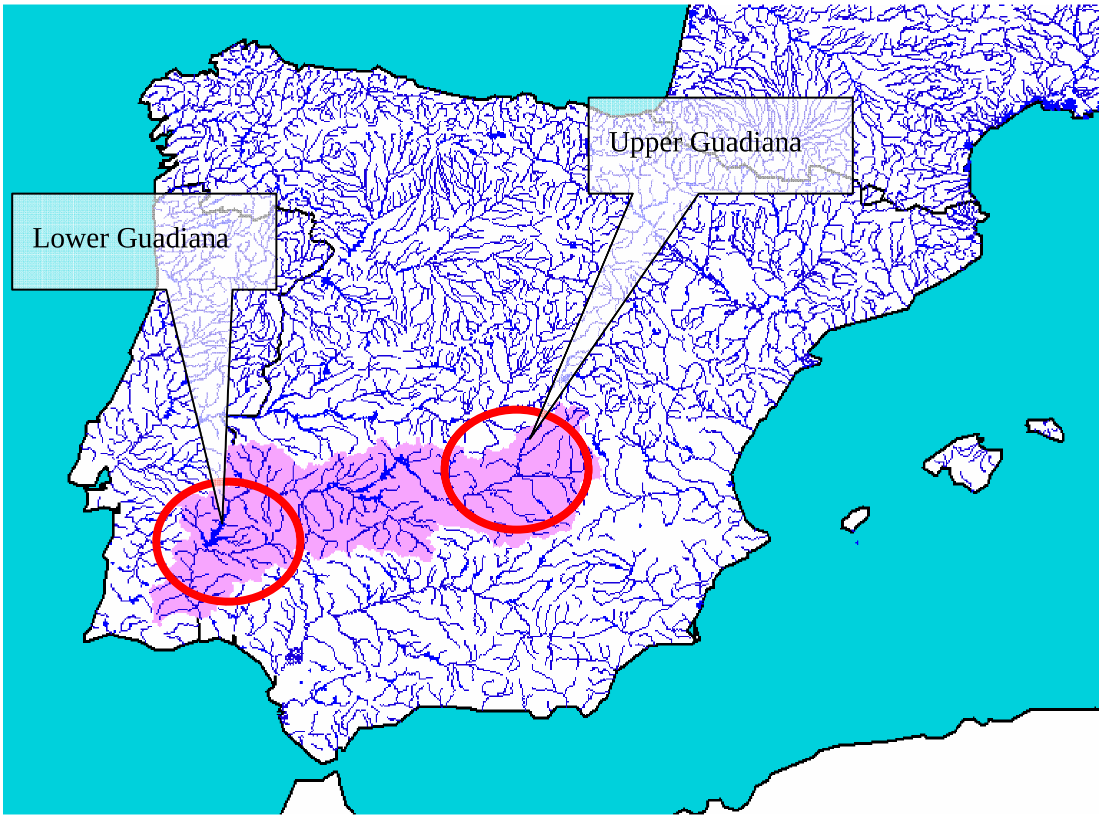


Figure 1: Guadiana basin

2.1 Upper and lower Guadiana basin, context and problematic

The Guadiana is an international river that originates in central Spain, flows through Portugal and finally reaches the Atlantic Ocean at the border between the two countries.

Following the discussion with stakeholders, WP 1.5 work is not covering the whole Guadiana basin but focuses on two systems from upstream and lower Guadiana:

- La Mancha Occidental Aquifer (Upper Guadiana),
- Caia Reservoir (Lower Guadiana).

The following paragraphs present briefly the context of water management issues in the two areas.

Upper Guadiana Basin (UGB)

As per the research action plan document (deliverable D 3.4.1 of NeWater project, see Llamas et al., 2005):

- "Water table drawdowns arising from uncontrolled groundwater withdrawals have caused some negative environmental impacts upon groundwater-dependent wetlands, streams and rivers. Perhaps the better known case of wetland degradation in the area is Las Tablas de Daimiel National Park".
- "Since the 1960s, intensive groundwater use for irrigation has become widespread in the region, triggering abundant social and economic benefits to a predominantly rural population."
- "Since water planners and decision-makers are inclined to focus on surface water infrastructures, intensive groundwater development is usually carried out by individuals. As a result, groundwater development is often anarchical from the outset, and eventually tends to raise concerns regarding its sustainability".
- About inter-basin transfer: "The Tajo-Segura transfer, operational since the late 1970s, is currently a subject for social and political controversies. (…) People in Castilla-La Mancha often contend they should have a priority over Tajo-Segura flows, since the transfer uptake is located in the Upper Tajo basin (which in turn lies within the Castilla-La Mancha autonomous community, see 3.3.1). Segura people usually flag their historical rights to the transfer in response to this claim."

The interested reader is referred to the research action plan for a more detailed vision of the complex social and environmental UGB context.

Lower Guadiana Basin

As per the research action plan document (deliverable D 3.4.1 of NeWater project, see Llamas et al., 2005):

"The region occupied in Portugal by the Guadiana basin is, in national terms, the region that presents the lowest GDP and higher social desertification index, a pronounced aging of the population, where the extensive agriculture has a big weight, with a service sector disseminated in small commerce and an industry of reduced expression.

With this level of economical development, water demand has been reduced and the gross water availability is in general enough to satisfy the current needs. However, during drought years, that frequently occur, the storing infrastructures do not have enough capacity to compensate an irregular temporal and spatial distribution of water resources. The construction of the Alqueva reservoir allows the regulation of the Guadiana river and make available an important volume for use in the basin and neighbour basins (Sado and Algarve).

Concerning surface water quality the situation is more worrying, including both the water coming from Spain as well as the northern part of the Portuguese basin, which is evidenced by the low water quality of the Portuguese reservoirs (Caia, Vigia, Monte Novo, Lucefit). This fact conditions the use of water, particularly for domestic use, as well as its environmental value for support of aquatic ecosystems, recreation and fishing."

2.2 Defining buffering capacity on the Guadiana basin

As there is no clear definition of BC in the scientific literature, deliverable D 1.5.1 of NeWater Report Series (2005) proposes a methodology to guide buffering capacity assessment with seven components to be defined :

1. Objective of buffering capacity assessment,
2. Nature of the buffer and buffering effects (who is buffering what?),
3. Temporal and spatial references,
4. Beneficiary (who is benefiting from the existence of the buffer?),
5. Driving forces whose impact on the beneficiary is reduced by the buffer ,
6. Associated water management strategies (description of action that can be undertaken to modify buffering capacity management),
7. Quantitative or qualitative nature of buffering capacity assessment methods,

Table 1 presents such an analysis applied to the context exposed in paragraph 2.1.

Table 1: Criteria to define buffering capacity components

Buffering capacity component	Upper Guadiana (Mancha Occidental aquifer)	Lower Guadiana (Caia dam)
Objective of buffering capacity assessment	Evaluate the long-term impact of groundwater management for the environment and the society	Reduce uncertainties in reservoir management by short to medium-term anticipation of drought conditions
Nature of the buffer	Mancha Occidental aquifer (UH04.04)	Caia reservoir (Portugal)
buffering effects	Temporary storage of water	Temporary storage of water
Temporal reference (time step of analysis)	Year	Month
Spatial reference	Guadiana basin upstream of El Vicario dam (16 000 km²)	Caia reservoir catchment (571 km²)
Beneficiary	• Farmers when using irrigation • Wetlands • future generations by preserving an exploitable groundwater resource	• Farmers when using irrigation • Village / City for water supply • Hydroelectricity • Caia River hydrosystem
Driving forces	• Rainfall on the Upper Guadiana • Evapotranspiration on the area • Transfer from the Tajo-Segura canal • Groundwater withdrawals rates	• Rainfall on the Caia catchment • Evapotranspiration on the area • Caia reservoir release and withdrawals management
Associated water management strategies	Reduction of groundwater withdrawals: • Modification of cropping patterns, • Improvement of irrigation techniques • …	Anticipation of water crisis: • Discussion with users to lower water allocations, • Increased storage to compensate for low inflows • …
Quantitative or qualitative nature of assessment methods	Qualitative & quantitative, based on probabilistic outputs of the bayesian networks	Quantitative, based on hydrological models outputs

2.3 Buffering capacity criteria

In the whole Guadiana basin, water management issues are mainly focused on the management of large storage of water used to satisfy uses concentrated in summer period. In the upper Guadiana, water storage is materialised by the Mancha Occidental aquifer. In lower Guadiana, artificial reservoirs such as the Alqueva or Caia reservoirs hold water in winter and release it in summer.

Hence, the identification of buffering capacity criteria in this context should be based on a notion of emptiness associated with a level of risk for the environment and the users.

However, as explained by Lerat et al. (2005): "We must be careful with the buffering concept. A quick analysis could lead us to a simple storage vision, which is a logical human behaviour: store when it is abundant to face droughts in the future. Such kind of definition could strongly orientate management strategy towards an increase of storage capacity: reservoirs capacity would then be seen as the only way to permanently increase buffering capacity". Hence the concept must be broadened to encompass a more environmentally-friendly perception of buffering capacity.

In the case of semi-arid catchment, the time frame is also a critical aspect of such a concept. This time frame can cover:

- Long term vision (several years): the issue is here the overall sustainability of water management.
- Short term to medium term vision (several weeks or month): the issue is the day to day allocation of scarce resources taking into account present and future hydrological conditions.

These two time-scales will constitute the basis for the identification of buffering capacity criteria on Guadiana basin.

In summarizing, buffering capacity criteria should qualify the filling level of the storage capacity in reference to risks for the users and the environment. The criteria should also refer to a time frame to reflect the dynamic aspects of buffering capacity.

Buffering capacity criteria for the Upper Guadiana

In this case, the buffering capacity is related to long-term objectives and can be defined by "the number of years required to obtain a recovery of wetlands under various management actions and economic scenarios".

This criterion is based on the preliminary scenarios (see Table 3 page 17) used in the development of Bayesian networks on the area, it encompasses the two notions mentioned previously:

- The "filling level" notion is integrated through the recovery of wetlands. Wetlands status is the most critical consequence of groundwater over-exploitation. Hence, wetlands recovery is the key variable to qualify the impact of aquifer management.
- The time frame is naturally present with the estimation of the number of years to reach the objective.

Note that the criterion presents an optimistic vision of buffering capacity in the area. A more pesimistic presentation could be based on the "number of years required to empty the aquifer and destroy the current buffering capacity of the groundwater system, e.g. by creating a set of irreversible conditions in the aquifer due to deterioration of groundwater quality by over-exploitating the aquifer.

Buffering capacity criteria for the Lower Guadiana

In this case, buffering capacity is defined each month as the reservoir filling deficit.

In a similar approach advocated by Palmer (1965) for the elaboration of the Palmer Drought Severity Index (PDSI), this deficit will be qualified in reference to :

- Normal values expected for the current month,
- Expected hydrological conditions for the coming month.

The final aim is to calculate a synthetic index informing water managers about the drought severity similar to the PDSI in the United States (see Figure 2).

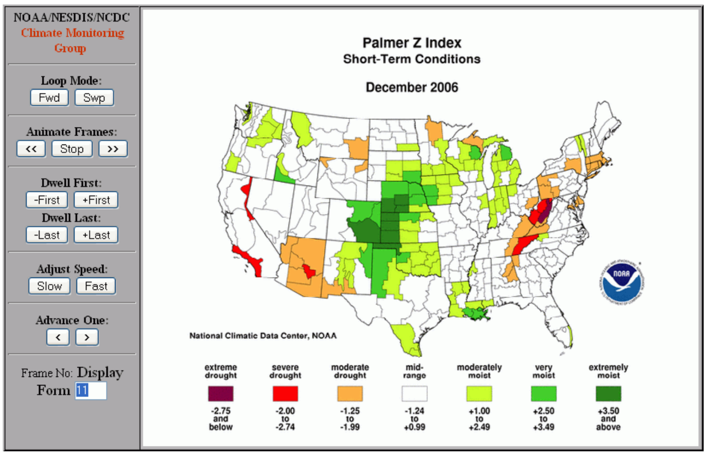


Figure 2: Palmer Drought Severity Index calculated by the National Climatic Data Center (USA)[1]

[1] Image retrieved from http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/zimage.html

3 Bayesian belief networks on the Upper Guadiana

This section describes the first domain model built in the Guadiana basin for the Upper part of the catchment. Its objective is to analyse how different management actions will influence irrigation water use, change in groundwater level, crop pattern, farmers income, wetland recovery, productivity and employment based on a knowledge integration technique known as "Bayesian belief networks".

3.1 Developing bayesian belief networks: objectives and methodology

A Bayesian belief network, also called a belief network (BN), is a type of decision support system based on probability theory which implements Bayes' rule of probability (Pearl, 1988; Cowell et al., 1999; Jensen, 2002; Henriksen et al., 2006, 2007; Bromley, 2005). This rule shows mathematically how existing beliefs can be modified with the input of new evidence. BNs organise the body of knowledge in any given area by mapping out relationships among key variables and encoding them with numbers that represent the extent to which one variable is likely to affect another.

BNs have gained a reputation of being powerful techniques for modelling complex problems involving uncertain knowledge and uncertain impacts of causes. Ideally, BNs is a technique to assist decision-making that is especially helpful when there is scarcity and uncertainty in the data used in taking the decision and the factors are highly interlinked, all of which makes the problem highly complex. The graphical nature of BNs facilitates formal discussion of the structure of proposed model and the ability of a BN to describe the uncertain relationships amongst variables is ideal to describe the relationship between events which may not be well understood.

In NeWater BNs belong as a tool to the theme: *participatory integrated assessment* mainly as part of *gap analysis.* On the basis of the established status and goals (IWRM step 1) and the existing policy, legislation and institutional framework a gap analysis is carried out to identify the further functions required to achieve the agreed goals.

As mentioned by Henriksen et al. (2007): "The management objectives for Upper Guadiana Basin (UPG) is to face and solve the problem of the current unsustainable abstraction of groundwater for irrigation purposes, causing severe negative impacts on wetlands and river system due to the significant lowering of the groundwater levels in the area, up to 50 meter.

The question that has to be answered in the test, is how do BNs support the specified requirements for PIA proposed by Jakeman and Letcher (2003) being problem focused, enhancing dialogue, being enriched by stakeholder involvement, connecting complexities and attempting to recognise missing essential knowledge."

<u>*Gap analysis*</u>

The gap analysis includes the following main processes (Keur et al., in prep.):

- **IWRM functions**. The task is here to identify the improvements/additions to the *existing management functions* that are required (including resource management functions such as formulation of policies for international co-operation on transboundary waters, water allocation and wastewater discharge permits, water resources assessments, monitoring, enforcement, mediation, training and information; *water services and infrastructure management functions* including frameworks for water services with the associated policies, laws, regulations and enforcements; and *financing functions and mechanisms* including items such as national and local capital markets and mechanisms like grants and internal sources, user payments, subsidies, loans and equity capital). The uncertainty relates mainly to the conceptual understanding (models) of social systems, multiple frames related to institutional framework, uncertainties related to water use efficiency standards with elements of both natural system understanding and new technological development. Furthermore there are scenario uncertainty related to future societal development (external social factors)

- **Gaps to meet water resources goals**. This implies to assess the gaps between the agreed goals and the status based on the present situation and the future pressures in terms of specific water resources issues such as water allocation, water quality and ecological status. The uncertainties are here mainly related to data and models of the natural system (Keur et al., in prep.).
- **Management potentials and constraints.** This implies to identify management potentials and constraints, e.g. in terms of SWOT analysis, at all levels, i.e. central, local and community, in the management hierarchy. The main source of uncertainty in this respect is the multiple frames among the different actors and the different management levels (ibid).

Participatory integrated assessment

Participatory Integrated Assessment (PIA) can be considered as a form of participatory policy analysis, which aims at supporting the policy process by designing and facilitating policy debate and argumentation. A wide range of participatory methods and techniques has been developed within the realm of disciplines such as social psychology, policy sciences, decision analysis and anthropology (Hisschemöller et al., 2001). Some of these are quite old, like brainstorming or decision seminars, others are of more recent date, such as policy exercises, consensus conferences and interactive technology assessment. The huge diversity of methods and techniques that are used in PIA basically reflect two main approaches to participation labelled the *cognitive approach* and the *argumentative approach (ibid).*

The cognitive approach departs from the observation that policy-makers (or water managers), because of their daily concerns, are not always open for information on complex issues. Preoccupied with the short term, they tend to neglect the long term. Especially in situations of high risk and pressure, they tend to narrow down their scope to their immediate network, which may lead to miscalculation of the problem situation and wrong decisions.

The argumentative approach starts with the observation that stakeholders from the policy and science communities are unlikely to improve their understanding of a complex problem situation, if they are provided with (new) factual knowledge. This is explained by the observation that ignorance does not primarily follow from a lack of information but from a lack of understanding of the conflicting assumptions underlying diverging viewpoints (multiple frames). Stakeholders may not only be unaware of each other’s assumptions, they may be unaware of their own assumptions as well.

The experiences of using Bayesian networks as a tool to help improve stakeholder participation in groundwater management has been revisited by interviewing water managers once involved in a Danish case study (Henriksen and Barlebo, 2007). The research from this case study has shown that Bayesian networks allow for the integration of different domains and knowledge bases, e.g. expert knowledge, modelling results and monitoring data from hydrology, economy, ecology and social domain. The water managers expressed, that the tool provided a focused dialogue and that it helped managers to evaluate different alternative actions and consequences in more depth. As one of the water managers expressed it. “I think the BNs could help to delineate the complexities and also handle some of the uncertainties that we are confronting, in terms of what is the value of the source of clean groundwater”. The interview supported the hypothesis developed in NeWater, that BNs as a tool are useful for participatory integrated assessment and social learning processes, and hence useful for adaptive management processes. We assume that BNs used in a dialogue with water managers and stakeholders allow for exploring cognitive as well as argumentative approaches of PIA. The objective is to test if BNs are helpful for gap analysis including the above purposes of such an analysis.

But in itself BNs do not allow a safe and transparent dialogue, the safety and transparency has to be enabled by the way the tool is used, which is the nature of the complex and uncertain participatory process, where learning is of significant importance. As the result of the MERIT project, prescriptions and guidelines for constructing BNs with stakeholders involvement have been developed based on four case studies which can be used as training material for water managers in how best to interactively construct BNs with stakeholder engagement. These guidelines should be followed and tested when using BNs for adaptive groundwater level management in the upper Guadiana basin.

Steps in construction of BNs as tool for participatory integrated assessment of gaps

The guidance from MERIT suggests that the BN construction follows a stepwise fashion with the following main steps (Bromley 2005), with feedback loop from Step 7 to 3:

- Define the context (Step 1)
- Identify factors, actions and indicators (Step 2)
- Build pilot network (Step 3)
- Collect data (Step 4)
- Define states (Step 5)
- Construct conditional probability tables (Step 6)
- Collect feed back from stakeholders (Step 7)

In Step 1, physical and socio-economic boundaries, area of interest, alternative scenarios, and indicators are defined. The degree of stakeholder involvement (information, consultation, active involvement or social learning is also determined). Afterwards, at meetings with stakeholders and general public, working groups are set up, stakeholder interests analysed and responsibilities clarified.

In Step 2, a list of stakeholder and general public concerns is drawn up, and actions to be taken and important indicators are defined. A synopsis of data sources, reports, stakeholders and models is described and agreed upon.

In Step 3, the important variables are identified, and directed edges are selected and connected. Rules for participation are also described, and the platform for information decided.

In Step 4, the data from different sources (including stakeholders and general public) are collected. Data are analysed and initially a simple BN is prepared as an illustration of what to do in the following steps. After feedback from stakeholders and public in Step 7, BNs are adjusted and refined with additional variables/links.

In Step 5, input from stakeholders and general public is important especially for indicator variables and actions. States are implemented in BNs for all variables.

In Step 6, constructing conditional probability tables (CPTs), includes a review of the networks at individual stakeholder meetings (planned to take place in Ciudad Real). Parameter learning is encouraged as a method of bridging data and CPTs. Inputs from domain models and experts is also part of this step in order to prepare all required quantitative informations for CPTs. BNs should also be carefully checked for internal consistency at this stage.

In Step 7, stakeholder and general public opinions on the final network are collected, and a conclusion based on the final BN is drawn. Furthermore, it is decided if additional adjustment of BN is required (feedback and carrying out Step 3-7 again). The final BN is documented and implemented in the decision support system (DSS), and used for describing the results of the alternative scenarios, which had been selected.

In Table 2 we summarise objectives and methodology for the application of BNs.

Table 2: Summary of objectives and methods for BN construction in the upper Guadiana. Steps are based on MERIT guidelines (Bromley, 2005) for participatory BN construction

MERIT guidelines step	Status	Comments
Step 1 Define the context	*Decided* Madrid 22-24 Nov 06	The BN network will deal with how different management actions influence irrigation water use, change in groundwater level, crop pattern, farmers income, wetland recovery, productivity and employment to Upper Guadiana Basin (UGB).
Step 2 Identify factors, actions and indicators	*Defined* Madrid 22-24 Nov 06	Actions are: Acquisition of water rights, Law enforcement, CAP subsidies and Annual management plans. Climate and initial state of aquifer are included as control factors. Indicators define groundwater levels and influence on wetland recovery, productivity, income and employment in the basin.
Step 3 Build pilot network	*Under construction* GEUS-CEH-WP3.4 15 Dec 06	A first line of variables, its definition and Hugin applied to the UGB (se figure 2). The contact people who are assisting from the Basin are from UCM and IGME. GEUS and CEH are the consultants.
Step 4 Collect data	*Collection started* Madrid 22-24 Nov 06	The situation of the UGB has been presented by UCM and IGME from the hydrological view point and considering mainly the water management. BH shall help decision-making related to Plan Especial del Alto Guadiana (PEAG)
Step 5 Define states	*Preliminary design* GEUS-CEH-WP3.4 15 Dec 06	A preliminary design of states has been accomplished based on inputs from Madrid workshop. Feedback from WP 4.3 and inputs to scenarios in December 2006 This design has to be discussed with stakeholders at the Ciudad Real meeting in April-May, and states evaluated
Step 6 Construct conditional probability tables (CPTs)	*Planned* Jan-April 2007	Based on feedback from WP 3.4 to pilot network and preliminary definition of states, the data for CPTs will be collected and included in a final BN for UGB during January-April 2007 to be ready for the workshop Step 7
Step 7 Collect feedback from stakeholders	*Planned* Ciudad Real April-May 2007	Short introduction to BN and presentation of network for UGB in Ciudad Real at workshop in April-May. Collection of feedback. Presentation at CAIWA 2007.

3.2 Variables included in the networks

The objectives of the UGB BN network is to analyse how different management actions will influence irrigation water use, change in groundwater level, crop pattern, farmers income, wetland recovery, productivity and employment to Upper Guadiana Basin (UGB).

A Bayesian network comprises three elements; first a set of variables that represent the factors relevant to a particular environmental system or problem, secondly the links between these variables and finally the conditional probability tables (CPTs) behind each variable that are used to calculate the state of the variable. The states of a variable represent all values that the variable can take. Where discrete variables are used the states can be described in any one of four ways:

1. As a set of labels; e.g. high, medium, low.
2. As a set of numbers; e.g. 10, 20, 30 etc.
3. As a set of intervals; e.g. 0 - 5, 5 -10, 10 -15 etc.
4. In Boolean form; e.g. true, false

A first set of variables and links for the BN (Figure 1) was prepared at the Madrid workshop and later modified through correspondence between the working group members.

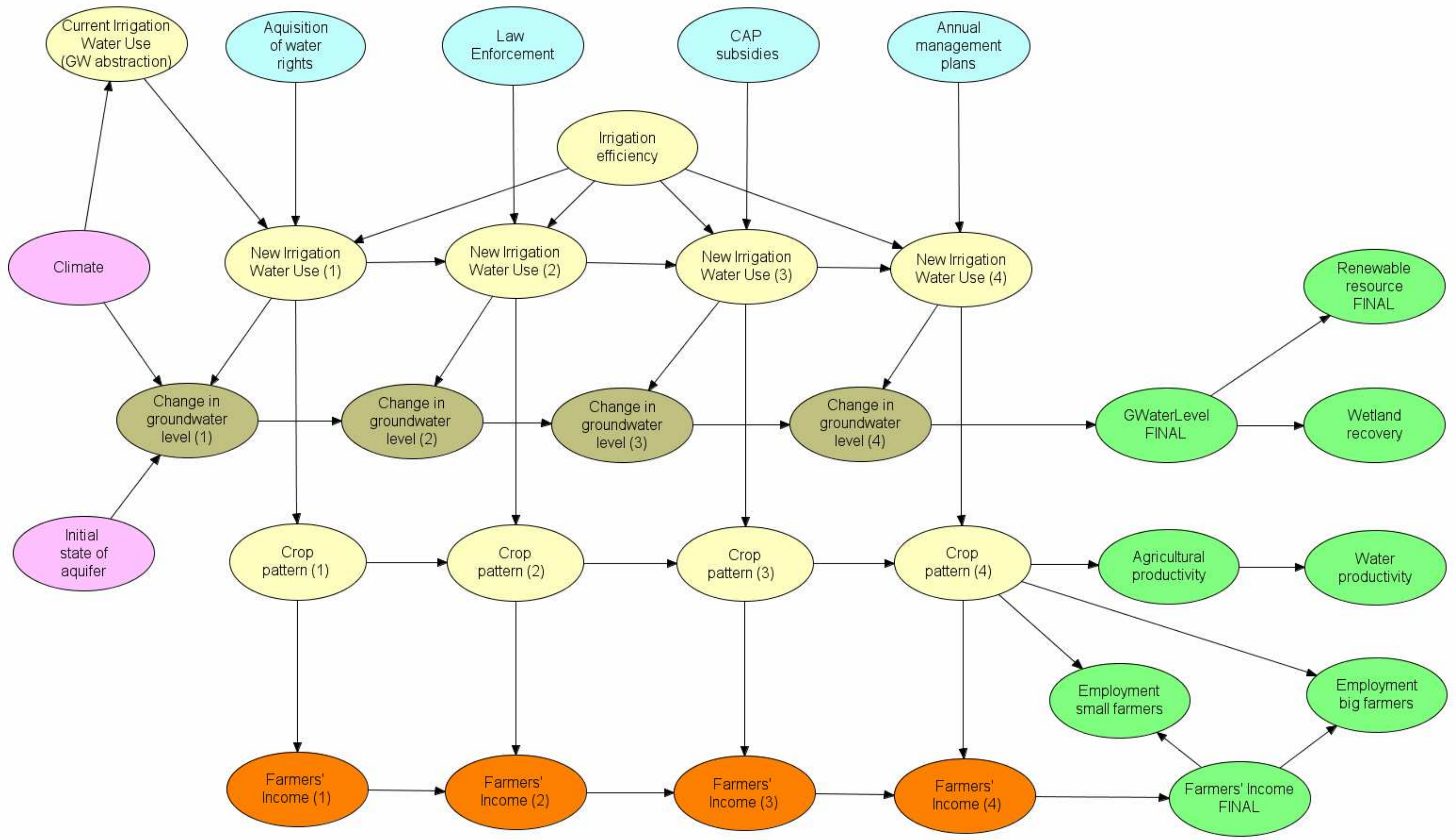


Figure 2: Pilot BN for UGB

Four preliminary scenarios (see Table 3) have been proposed: two with business as usual and no recovery of the wetlands and two with serious restrictions on the economic agricultural output (with technology as usual) and a good recovery of the wetlands.

Table 3: Preliminary scenarios

Scenario	Agricultural output (M€)	Change in water level (m)	Recovery of Wetlands (years)
A1	1000	-0.4 m	never
A2	900	-0.08	never
B1	510	+1.84	20 – 25
B2	490	+2.00	15-20

More details about the agricultural scenarios can be found in Varela-Ortega et al. (NeWater document of 28.11.2006). In future simulations we should consider options that enable to recover the water levels without negatively affecting the agricultural inputs as severe decreases are unacceptable from a social point of view. Possible solutions are changes in crop patterns towards more profitable crops and improvement of irrigation technology.

A preliminary description of states has been accomplished based on the inputs from Madrid workshop and from feedback from WP 4.3 and inputs to scenarios in December 2006 (Table 2).

Table 4: Variables and states of the Bayesian network

Variable	**Description of variable**	**States**	**Data source *)**
Acquisition of water rights	States: Sold water rights in million m3 per year for the whole UGB.	• 0 - 50 • 50 - 100 • 100 - 150 • 150 - 200	For the time being, this variable is considered in a general way in the UPM scenario.
Law enforcement	States in mill m3 / year. Both illegal and people pumping too much.	• Reduce nothing, : Illegal boreholes (legal 50,000 ha) • Reduce 35 mill m3: Illegal boreholes + people pumping above licence • Reduce 70 mill m3, : Expert opinion. Not only illegal, also water pumping too much water	For the time being this variable is considered in a general way in scenarios A and B by UPM.
CAP subsidies	Common Agricultural Policy (CAP) programs: CAP option 1: coupled payments CAP option 2: decoupled payments	• A: CAP 1 • A: CAP 2 • B: CAP 1 • B: CAP 2	For the time being, this variable is considered in a general way in the UPM scenario.
Annual management plans	States: Permitted water abstraction for Aquifer 23 (mill m3/year).	• 200 • 350 • 400	For the time being, this variable is considered in a general way in the UPM scenario

Variable	**Description of variable**	**States**	**Data source *)**
Climate	Annual precipitation: Very dry < 320 mm (15 %) Dry 320 - 370 (20 %) Average 370 - 460 (30%) Humid 460 - 530 (20%) Very Humid >530 (15%)	• Very dry • Dry • Average • Humid • Very humid	
Initial state of aquifer	States: Groundwater level above or below threshold of -3 meters Note: We assume that the initial water level is -30 below the Las Tables National Park bottom.	• Above threshold • Below threshold	
Current irr water use (gw abstraction)	States: Mill m3 / year, abstracted from the whole UGB.	• 200 - 250 • 250 - 300 • 300 - 350 • 350 - 400 • 400 - 450 • 450 - 500 • 500 - 550 • 550 - 600	
Irrigation efficiency	High / Low Current situation acceptable (vineards with drip irrigation, cereals with strip...)	• High • Low	
New irrigation water use	This node represents the current water use minus the amount of water purchased by acquisition / law enforcement / CAP subsidies / annual managmt. plans	• 2 - 2.5 • 2.5 - 3 • 3 - 3.5 • 3.5 - 4 • 4 - 4.5 • 4.5 - 5 • 5 - 5.5 • 5.5 - 6	
Change in groundwater level	Annual change in groundwater level (m)	• decrease > 0.5 m per year • decrease 0-0.5 m per year • steady state • increase 0-0.5 meter per	

Variable	Description of variable	States	Data source *)
		year • increase >1 meter per year	
Crop pattern	This node describes the major crop types. They should be grouped in terms of their water use so that for example olives + vines may be representative of low water use crops whereas maize might be a higher use.	• Cereals • Maize • Horticultural crops • Melons • Vine • Other • Set aside	Need to consult agricultural experts.
Farmers' income	This represents farmer's income, the soil interest rate: euro/ha.	• 0 - 100 • 100 - 200 • 200 - 300 • 300 - 400 • 400 - 500 • 500 - 600	
Groundwater level, final	Annual change in groundwater level: + increase, - decrease. The states refer to water tabel level in aquifer 23.	• -1 - -0.6 • -0.6 - 0 • 0 - 2 • 2 - 3	
Renewable resource, final	States: Renewal resource is 425 mill. m3 per year if water level depth is above -3 meters, else 300 mill. m3. Renewable resource when the water level depth is lower than ?3 meters is 500 mill. m3.	• 300 • 425 • 500	
Wetland recovery	States: Years for recovery of wetlands, Las Tablas da Daimiel.	• 15-20 years • 20-25 years • Never	
Agricultural productivity	States units: mill. euro.	• 400 - 500 • 500 - 600 • 600 - 800 • 800 - 900 • 900 - 1000	Agricultural production data have been calculated based on statistical information of the Spanish Ministry of Agriculture (MAPA) and the Agriculture Department of

Variable	Description of variable	States	Data source *)
			the Regional Government of Castilla-La Mancha. Field work data and modeling results elaborated by UPM team have been also used. Disaggregated data for each crop have been used to calculate total values.
Water productivity	States units: euro/m3 Water productivity: Total agricultural production per total water abstractions	• 1.25 - 1.5 • 1.5 - 1.75 • 1.75 - 2 • 2 - 2.25	Total agricultural production and total water abstractions have been used to calculate water productivity rates. These rates are consistent with the equivalent rates of the National Irrigation Plan of Spain (Plan Nacional de Regadios, MAPA.
Farmers income, final	This represents farmers income, the soil interest rate: euro/ha.	• 0 - 100 • 100 - 200 • 200 - 300 • 300 - 400 • 400 - 500 • 500 - 600	
Employment small farmers	First approximation: Increase / decrease. Second app: Number of jobs per m3. Small farmers versus Big farmers. Horticulture crops is a social crop (create labour). If you let people use less water everybody will be unemployed.	• Increase jobs small farmers • No change • Decrease jobs small farmers	
Employment big farmers	See “employment small farmers”	• Increase jobs big farmers • No change • Decrease jobs big farmers	

*) The collection of data continues along with the construction of the conditional probability tables (see Table 2 and paragraph 3.3).

3.3 Probability density tables

The next step is to complete the conditional probability tables (CPT) that lie behind each of the variable. This is a task that requires care and patience because if the CPTs are wrong, the network output will be equally wrong. The procedure used to complete CPTs in the Upper Guadiana Basin is based on existing expert knowledge, modelling results, monitoring data and stakeholder opinion/knowledge.

For each variable, the complexity and size of the CPT depends on the number of parents and states of the variable; the more parents and states, the greater the size and complexity of the tables. Table 5 provides an overview:

Table 5: Description of CPT complexity based on number of parents and states

Variable	Number of parents	Number of states	Size
Acquisition of water rights	0	4	1 x 4 = 4
Law enforcement	0	3	1 x 3 = 3
CAP subsidies	0	4	1 x 4 = 4
Annual management plans	0	3	1 x 3 = 3
Climate	0	5	1 x 5 = 5
Initial state of aquifer	0	2	1 x 2 = 2
Current irr water use (gw abstraction)	1	8	1 x 5 x 8 = 40
Irrigation efficiency	0	2	1 x 2 = 2
New irrigation water use (1&3) (2&4)	 3 3	 8 8	 2 x 4 x 8 x 8= 512 2 x 3 x 8 x 8 = 384
Change in groundwater level (1) (2-4)	 3 2	 5 5	 2 x 5 x 8 x 5 = 400 8 x 5 x 5 = 200
Crop pattern (1) (2-4)	 1 2	 7 7	 8 x 7 = 56 8 x 7 x 7 =392
Farmers' income (1) (2-4)	 1 2	 6 6	 7 x 6 = 42 6 x 7 x 6 = 256
Groundwater level, final	1	4	5 x 4 = 20
Renewable resource, final	1	3	4 x 3 = 12
Wetland recovery	1	3	4 x 3 = 12
Agricultural productivity	1	5	7 x 5 = 35
Water productivity	1	4	5 x 4 = 20
Farmers income, final	1	6	6 x 6 = 36
Employment small farmers	2	3	7 x 6 x 3 = 126
Employment big farmers	2	3	7 x 6 x 3 = 126
Total of BN			**5284**

The population of the BN is planned to take place during January-April 2007. For management variables (water rights, law enforcement, CAPs and annual management plans) a value of 1 is simply added to each variable. When running the BN combinations of actions can be chosen and calculated. For the parent variables climate, initial state of aquifer and irrigation efficiency best estimates of distributions can be added to the BN for current situation. This part of the network can be populated relatively fast.

Some variables table require more patience and more work to fill. Especially the four ‘strings’: new irrigation water use, change in groundwater level, crop pattern and farmers income will require a proper assessment process drawing on both expert knowledge, modelling data etc. Many of these relationships can be established and entered and the resulting probability distributions examined compared with existing knowledge, e.g. summary of scenarios estimates for scenario A1, A2, B1 and B2 with agricultural output, change in water level and recovery of wetlands. Some combinations of states will be known from models and expert knowledge, others has to be carefully assessed in a dialogue between domain experts and BN constructors.

The indicator variables (the green variables) will probably require both expert inputs and opinions from stakeholders. It is therefore very important to allow a transparent process when the CPTs are entered, and space and time for discussion. This is planned to take place at a workshop in Ciudad real in in April or May 2007, where feedback on variables, links, states and CPTs will be collected and reassessed. Below is shown a simple example of one relatively simple CPT for the variable Current Irrigation Water Use (Table 6). Different methods are available for populating BNs with CPT, see Bromley (2005).

Table 6: Example of CPT: Current Irrigation Water use, variable C15 (preliminary data). The variable has one parent variable which is climate (variable C6). For each state of climate a conditional probability table has to be specified describing irrigation water use probability distribution. It is assumed that wet climate, requires less irrigation water use (1 parent x 5 states of parent x 8 states of variable = 40 probabilities to be specified)

Current IrrigationWater Use(GW abstraction)(C15)

C6	Very dry	Dry	Average	Humid	Very hur
200 - 250	0.0	0.0	0.0	0.0	0.0
250 - 300	0.0	0.0	0.0	0.0	0.0
300 - 350	0.0	0.0	0.0	0.0	0.1
350 - 400	0.0	0.0	0.05	0.1	0.35
400 - 450	0.0	0.1	0.15	0.35	0.35
450 - 500	0.2	0.3	0.35	0.35	0.15
500 - 550	0.5	0.4	0.35	0.15	0.05
550 - 600	0.3	0.2	0.1	0.05	0.0

4 Hydrological models on the lower Guadiana

This section describes the second domain model built in the Guadiana basin for the lower part of the catchment and more precisely for the Caia reservoir system. Its objective is to provide a robust tool to calculate drought severity indicators adapted to reservoir management.

4.1 Modelling reservoir management strategies: objectives and methodology

The buffering capacity concept finds its best application in the management of reservoirs: in this case, the infrastructure is made to store water temporarily in an artificial buffer (the reservoir) and to release it when required.

The greatest challenge with reservoirs in arid or semi-arid countries is to combine day to day allocation of resources and medium-term vision of the hydrologic situation particularly in drought conditions. In Guadiana for example, the consequences of one year of drought can persist over several years as stated by Lerat et al. (2006) for the Caia reservoir in Portugal, hence a mismanagement on a single year can threaten the equilibrium of the system for a much longer period.

To face such complex situations, water managers need to constantly anticipate crisis situations based on two elements:

Phase 1. **Estimation of present and future hydrological driving forces**: this phase aims to estimate the present and future state of the groundwater and surface water systems based on observed data (monthly rainfall for example), statistics (deviation from normal situations) and forecasting models (meteorological and hydrological). This first step allows to define the degree of emergency and the range of possible actions.

Phase 2. Set-up of an **action plan for the coming month regarding water allocations to users** (from groundwater, rivers and reservoirs). This second step converts the knowledge on hydrological driving forces into operational procedures of reservoir management.

Reservoir management in the litterature

Reservoir management is probably one of the oldest question studied in hydrology. This paragraph provides a very short overview of the abundant literature on the subject. Classically, research programs concentrate either on the estimation of hydrological driving forces (phase 1 in the preceding paragraph) or on real-time procedures to optimise water allocation (phase 2).

Phase 1 activities encompass all the researches devoted to long term streamflow and rainfall forecasting. Due to large uncertainties in rainfall forecasts, this works generally include a stochastic component (see for example Araghinejad, 2006, or Regonda, 2006, for recent references on subject). To deal with the inherent complexity of the natural system, recent works mainly focus on non-parametric techniques such as the bootstrap resampling described by Lall and Sharma (1996). Deterministic approaches rely on coupled meteorological and hydrological models as presented by Tucci (2003) for the Uruguay river. The key element in all these developments is to successfully include climate predicators like the North Atlantic Oscillation (Wedgbrown, 2002), the well known Palmer Drought Severity Index used by the United States administration (Palmer, 1965) or indices related to "El Ninõ" events (Poveda et al., 2001).

Surprisingly, there are few studies connecting phase 1 and phase 2 activities. The latest is devoted to optimal real-time procedure to allocate scarce resources in an unknown future. Phase 2 researches are strongly oriented toward the application of mathematical optimisation frameworks such as the linear programming (Ozelkan, 1997). These frameworks generally require strong assumptions on reservoir inflows statistical properties (normality of residuals for example). Yeh (1985) provides an extensive review of this techniques applied to reservoir management, he also remarks that they are rarely put into practice due to their low acceptance by water managers. Yang et al. (1991, 1995) suggest another mathematical approach of the same question based on a simple hydrological model and Monte-Carlo simulations.

Many tools provides solutions to apply optimisation algorithms to practical cases. Eight of them have been reviewed by Lerat et al. (2005).

General objective of the study

The objective of work package 1.5 is to develop an integrated modelling framework able to produce long-term inflow forecasts and propose robust methods to manage the reservoir in operational conditions. This approach will be applied to Caia reservoir in Portugal with the following phase:

Phase 1. Calibrate a simple and deterministic model able to simulate the evolution of stored volumes in the reservoir based on catchment rainfall and withdrawals from the reservoir.

Phase 2. Develop a rainfall generator based on the K-nearest neighbour resampling techniques (Lall and Sharma, 1996) to produce stochastic rainfall forecasts.

Phase 3. Combine the deterministic model and the rainfall generator and define a set of indicators on drought severity.

This report presents only the first phase considered as the development of the "catchment domain model" (title of the present deliverable). Phase 2 will be described in deliverable 1.5.5 ("Rainfall simulation toolbox"), Phase 3 will be described in deliverable 1.5.6 ("Methods to use the domain models in an adaptive management perspective").

Figure 3 presents the location of Caia reservoir. The gauging station of Puente on the Guadiana river is located at the Spanish/Portuguese border.

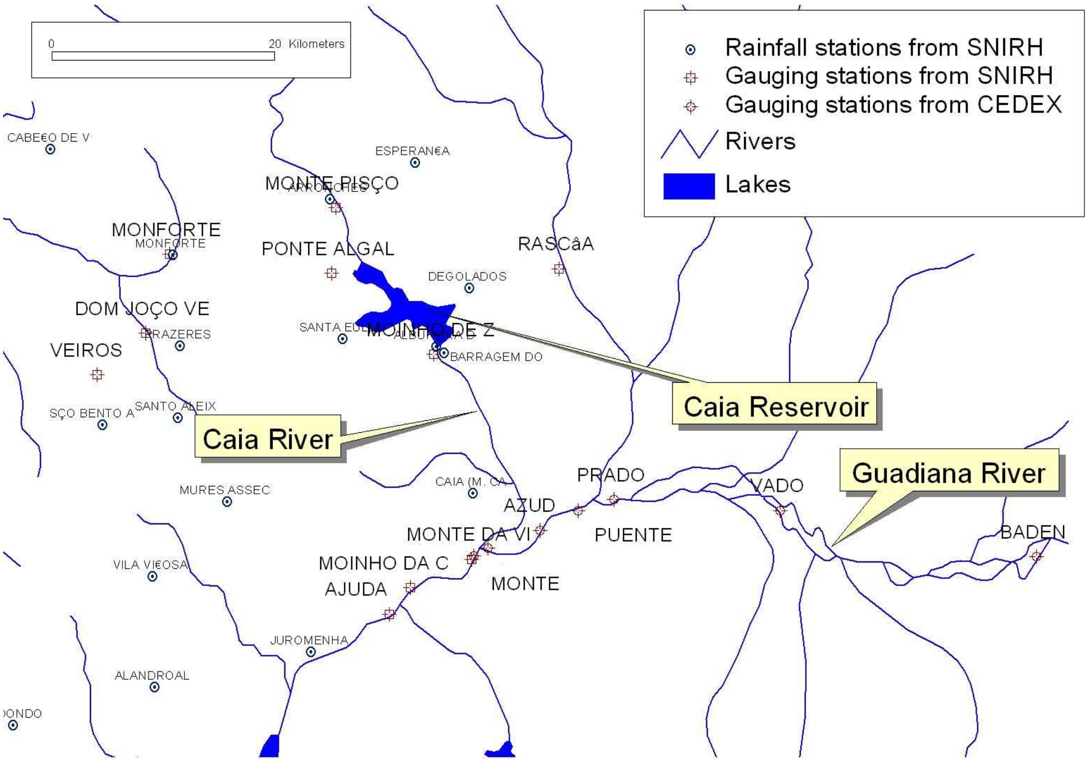


Figure 3: Caia Reservoir location

4.2 Model set-up

Model structure

The choice of the time-step is dictated by data availability: rainfall and volumes data are available at the daily time step but water uses are only available at the monthly time step (Lerat et al., 2006). Hence the monthly time-step is selected.

In our study, a model is used to calculate the stored volumes in the Caia reservoir at the end of each month based on rainfall, evapotranspiration and water withdrawals during the month. This calculation is performed in two steps:

1. **Calculation of inflows to the Caia reservoir from the corresponding catchment,**
2. **Calculation of stored volume at the end of the month.**

Point 1 is treated using the GR2M hydrological model (see next paragraph). Note that GR2M consistency can be checked independently on streamflow data from Ponte Algalé and Monte Pisao stations. These two stations are located immediately upstream of the Caia reservoir and cover a catchment of 345 km² (222 for Monte Pisao and 123 for Ponte Alagalé, see Lerat et al., 2006). Hence, they provide an interesting estimation of reservoir inflows. Unfortunately streamflow data are only available for the period 1982-1990, a period during which water use data are missing.

Point 2 calculations are based on a simple conservation of mass equation applied to the Caia reservoir:

$$VOL(m+1) = VOL(m) + GR2M\left[X_{CAIA}, R_{catch}(m), PE_{catch}(m)\right] + R_{res}(m) - E_{res}(m) - US(m)$$

(Eq. 1)

Where:

VOL(m)	Stored volume at the end of month "m" (in millions m3/month)
GR2M (…)	Mean monthly inflow to the Caia reservoir during month "m" simulated with GR2M model (in millions m3/month)
X_{CAIA}	GR2M model parameter for the Caia reservoir catchment
R_{catch} (m)	Monthly rainfall for month "m" over the Caia catchment (in millions m3/month)
PE_{catch} (m)	Monthly potential evapotranspiration for month "m" over the Caia catchment (in millions m3/month)
R_{res} (m)	Monthly rainfall for month "m" over the Caia reservoir
E_{res} (m)	Monthly evaporation for month "m" over the Caia reservoir
US(m)	Water uses from the Caia reservoir during month "m" (in millions m3/month)

The resulting model architecture is presented on Figure 4, **its output is a time-series of monthly stored volumes (or water levels) in the Caia reservoir and its inputs are:**

- **Monthly rainfall on the Caia catchment and on the Caia reservoir,**
- **Monthly potential evapotranspiration from the Caia catchment and evaporation from the Caia reservoir lake,**
- **Monthly water withdrawals from the Caia reservoir (water uses and downstream releases).**

Within this model, **two parameters of the GR2M rainfall-runoff model have to be calibrated against observed data.**

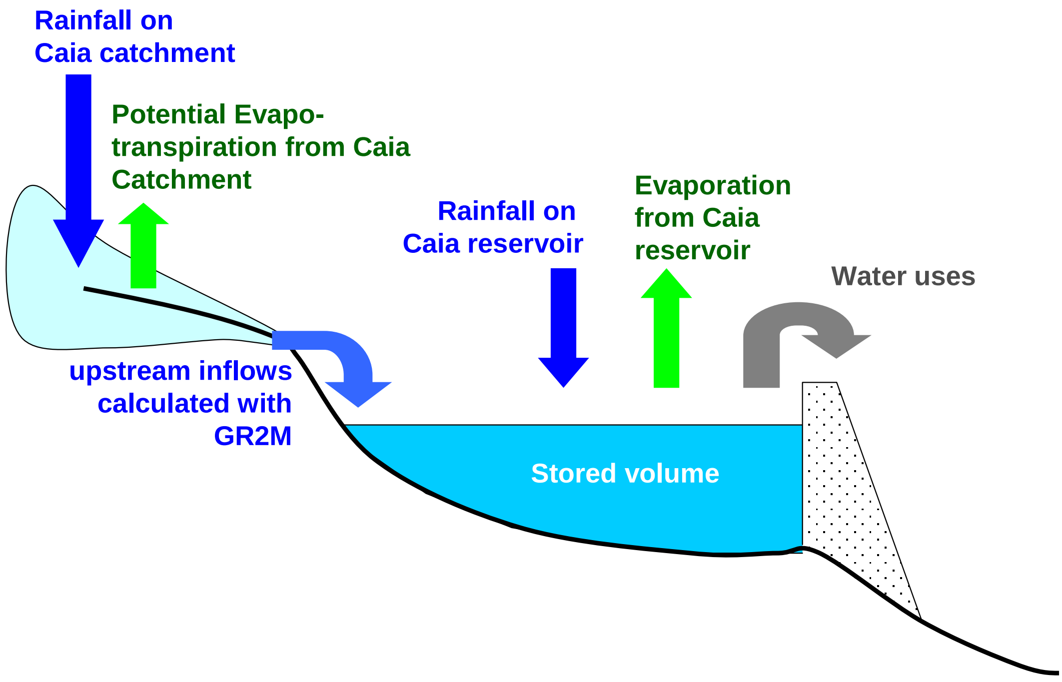


Figure 4: Model structure used to simulate monthly stored volumes in the Caia reservoir

GR2M hydrological model

The GR2M model is a simple lumped rainfall-runoff model, running at a monthly time step. It was developed for applications in water resources assessment and management. Its simple structure and its limited data requirements make it very suitable for applications in operational conditions.

A detailed description of the model is provided by Mouelhi et al. (2006). Information can also be found on the following Web site: http://www.cemagref.fr/webgr/.

The model structure (see Figure 1) is based on a production function and a transfer function:

- the production function uses on a soil moisture accounting (SMA) store and a water exchange function (to account for exchanges with the outside of the catchment);
- the transfer function only uses a quadratic routing store (fixed capacity equal to 60 mm).

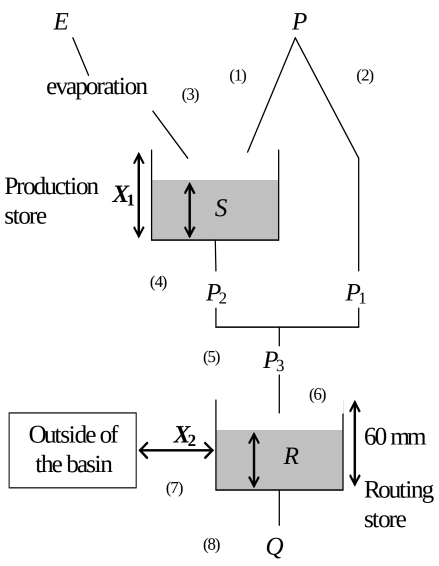
The model has only two parameters to calibrate:

- X1 : the capacity of the SMA store (mm)
- X2 : the groundwater exchange coefficient (dimension less)

The model requires as only inputs:

- Observed monthly time series of catchment areal rainfall;
- Observed monthly time series of potential evapotranspiration.
- Observed streamflow time series is only needed for model parameter calibration.

The model was tested in various climatic and hydrological conditions and proved to be as efficient as other models of the same type (see Mouelhi et al., 2006).



(1) $$S_1 = \frac{S + X_1\varphi}{1+\varphi\frac{S}{X_1}} \quad \text{with} \quad \varphi = \tanh\left(\frac{P}{X_1}\right)$$

(2) $$P_1 = P + S - S_1$$

(3) $$S_2 = \frac{S_1(1-\psi)}{1+\psi\left(1-\frac{S_1}{X_1}\right)} \quad \text{with} \quad \psi = \tanh\left(\frac{E}{X_1}\right)$$

(4) $$S = \frac{S_2}{\left[1+\left(\frac{S_2}{X_1}\right)^3\right]^{1/3}}$$

(5) $$P_2 = S_2 - S \qquad P_3 = P_1 + P_2$$

(6) $$R_1 = R + P_3$$

(7) $$R_2 = X_2.R_1$$

(8) $$Q = \frac{R_2^2}{R_2 + 60}$$

Figure 5: Sketch of the GR2M model (E: potential evapotranspiration; P: rainfall; Q: streamflow; X1 and X2: model parameters; the other letters are model internal state variables)

Calibration and validation procedure

Calibration aims to identify optimal sets of parameters for the model presented on Figure 4. The calibration is performed with a Levenberg-Marquardt algorithm available within the Scilab software (Scilab consortium, 2006).

The data use to calibrate and validate the model are presented by Lerat et al. (2006). They consist in a monthly data set starting in January 1990 and ending in March 2000. It contains:

- Caia reservoir catchment rainfall calculated as a arithmetic average of 5 rainfall stations (Alegrete, Arronches, Degolados, Esperança and Santa Eulalia) from the Insituto do Agua Web site (INAG , 2006).
- Caia reservoir catchment potential evapotranspiration (PE) calculated as a arithmetic average of 3 meteorological stations (Evora, Porto Alegre and Badajoz in Spain). PE is calculated by the formula suggested by Oudin et al. (2005) out of mean monthly temperature data from the Global Hydrological Climatological Network (Vose et al., 1992).
- Stored volumes in Caia reservoir from the Instituto do Agua Web site (INAG, 2006).
- Releases and water uses from Caia reservoir from the Instituto do Agua Web site (INAG, 2006).
- Monthly stream flow data from Monte Pisao and Ponte Algalé stations (for the independent check of GR2M) from the Instituto do Agua Web site (INAG, 2006).

As advocated by Klemes (1986), the dataset is split into two periods to calibrate the model and validate it on an independent dataset:

- P1: From January 1990 to December 1994,
- P2: From January 1995 to March 2000.

Model adequacy is assessed by comparing visually observed and calculated values. The Nash-Sutcliffe criteria (Nash and Sutcliffe, 1970) is also utilised to give a more objective estimation of model performance :

$$NS = \left[1 - \frac{\sum_{i=1}^{N}\left(D_i - \hat{D}_i\right)^2}{\sum_{i=1}^{N}\left(D_i - \overline{D}_i\right)^2}\right] \times 100 \quad \textit{(Eq. 2)}$$

where N is the number of days of simulation, D_i is the observed data on month i, $\hat{D}_i$ is the data calculated by the model on the same month, and $\overline{D}_i$ is the mean observed data on the test period. In validation mode, $\overline{D}_i$ is calculated from the validation period and not from the calibration period.

The model is perfect with NS criteria of 100%. With 0%, the model is equivalent to a elementary model attributing the mean value at each time step.

4.3 Model results

GR2M consistency tested on upstream streamflow data

Table 7 presents the results of GR2M model expressed with the Nash-Sutcliffe criteria calculated on discharges and log-transformed of discharges (to give more importance to low flow periods). Figure 6 shows the corresponding hydrographs.

GR2M appears to be able to represent hydrological behaviour of the Caia reservoir catchment: the performance is satisfactory from a numerical and graphical point of view. Table 8 details the parameters of GR2M calibrated on both catchment and on the sum of discharges from Monte Pisao and Ponte Algalé. The parameters are stable across the periods and over the catchment with a capacity of soil moisture accounting reservoir between 150 and 200 mm and a groundwater exchange coefficient between 0.7 and 0.9.

Table 7: Nash-Sutcliffe criteria of GR2M model applied to gauging stations of Monte Pisao and Ponte Algalé (upstream of Caia reservoir)

Stations	NS criteria in validation mode on streamflow data Period P1	NS criteria in validation mode on streamflow data Period P2
MONTEPISÃO	90.3	86.6
PONTE ALGALÉ	89.8	74.0
Sum of both	97.0	97.5

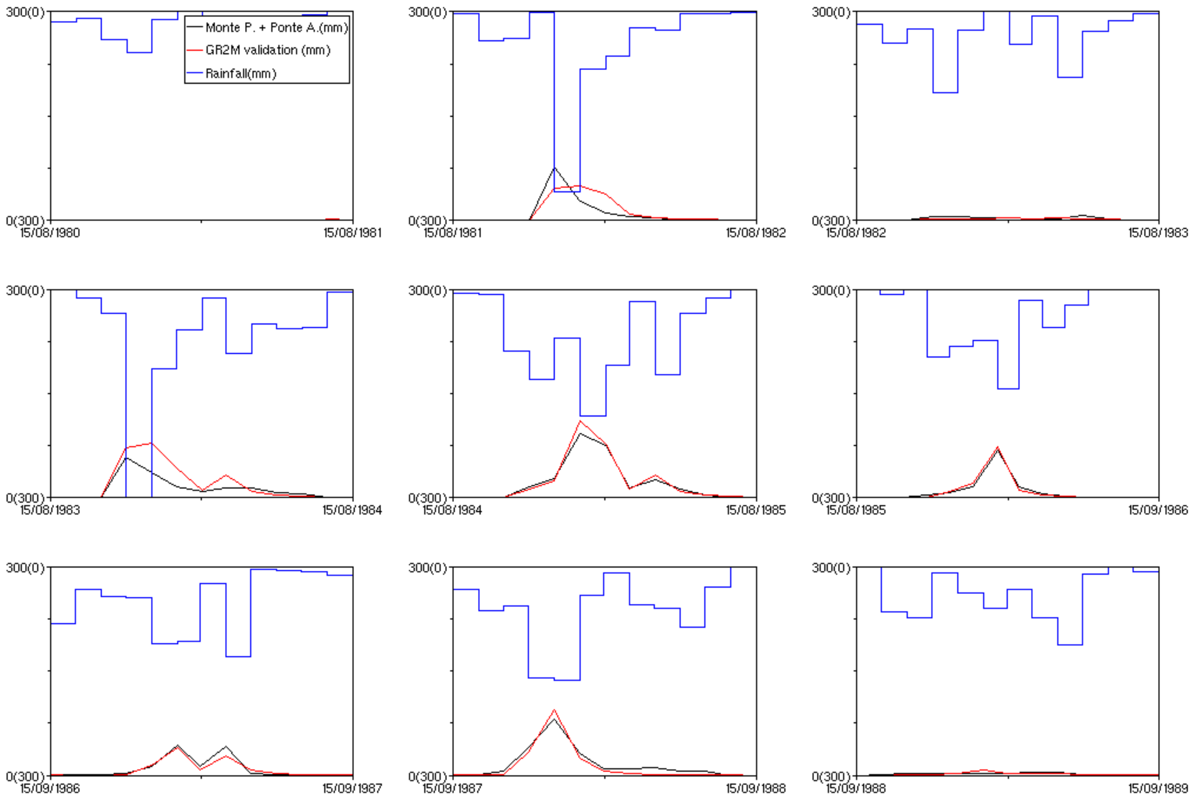


Figure 6: GR2M simulation in validation mode versus observed data (sum of discharges from Ponte Algalé and Monte Pisao)

Table 8: GR2M parameters on gauging stations of Monte Pisao and Ponte Algalé (upstream of Caia reservoir)

Stations	Size of SMA store on period P1	Groundwater losses parameter on P1	Size of SMA store on period P2	Groundwater losses parameter on P2
MONTEPISÃO	155	0.78	303	0.95
PONTE ALGALÉ	188	0.68	145	0.77
Sum of both	176	0.83	201	0.89

In conclusion, GR2M model appears to be well suited the hydrology of the Caia reservoir catchment in spite of its pronounced aridity.

Problems with the stored volumes and water withdrawals data, proposed correction

Despite the encouraging results obtained with GR2M model, initial works on model calibration for the overall system (GR2M + Caia reservoir, see Figure 4) lead to poor results. Hence a simple verification of the consistency of water uses and stored volumes data has been undertaken: the idea was to estimate inflow to the Caia reservoir from the available data.

At each time step the following variable was calculated (same notations than *(Eq. **1*** page 26):

$$INF(m) = VOL(m) - VOL(m-1) - R_{res}(m) + E_{res}(m) + US(m) \quad (\textit{Eq. 3})$$

INF(m) is the inflows reservoir required to close the mass balance equation of the Caia reservoir. The results are presented on Figure 7.

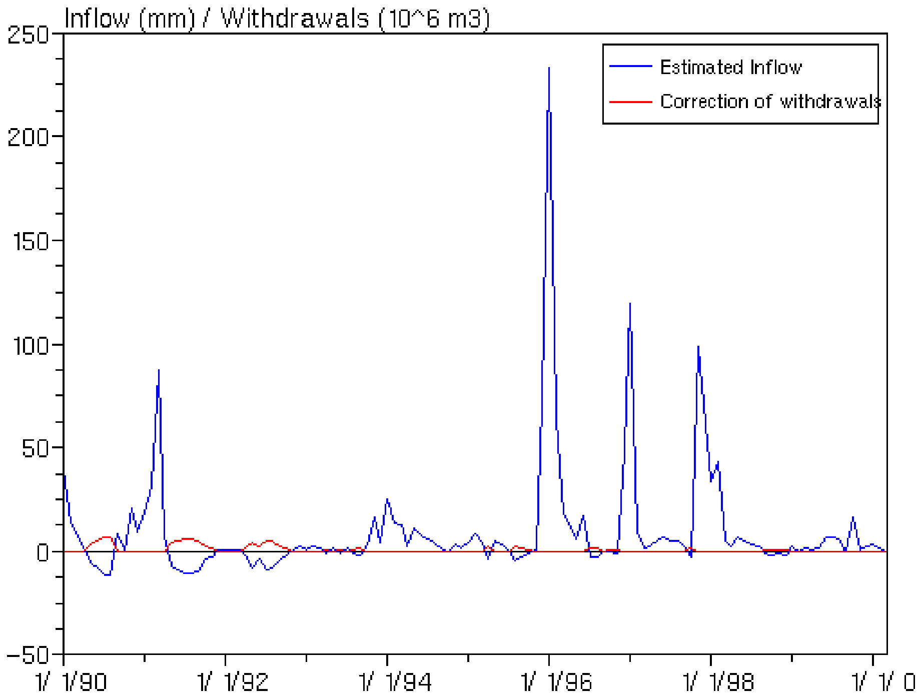


Figure 7: Estimation of Caia reservoir inflows based on stored volumes and water withdrawals data

The striking fact revealed by Figure 7 is that estimated inflows can be negative during several periods. **This is not physically possible, in fact during such periods the decrease of the stored volume is greater than the sum of all losses from the reservoir** (sum of water withdrawals and atmospheric losses). This traduces either error in stored volume data or in reservoir losses. The most probable hypothesis is an underestimation of water withdrawal from the reservoir.

Hence, to correct the data and calibrate our model on the reservoir system, we propose to increase the water withdrawals to avoid negative values of estimated inflows as per equation 3. The resulting correction is presented on Figure 7. Figure 8 compares this correction with the sum of withdrawals.

Figure 8 reveals that the correction is nearly negligible for the year 1993 to 2000 but important for the summer periods of years 1990 to 1992.

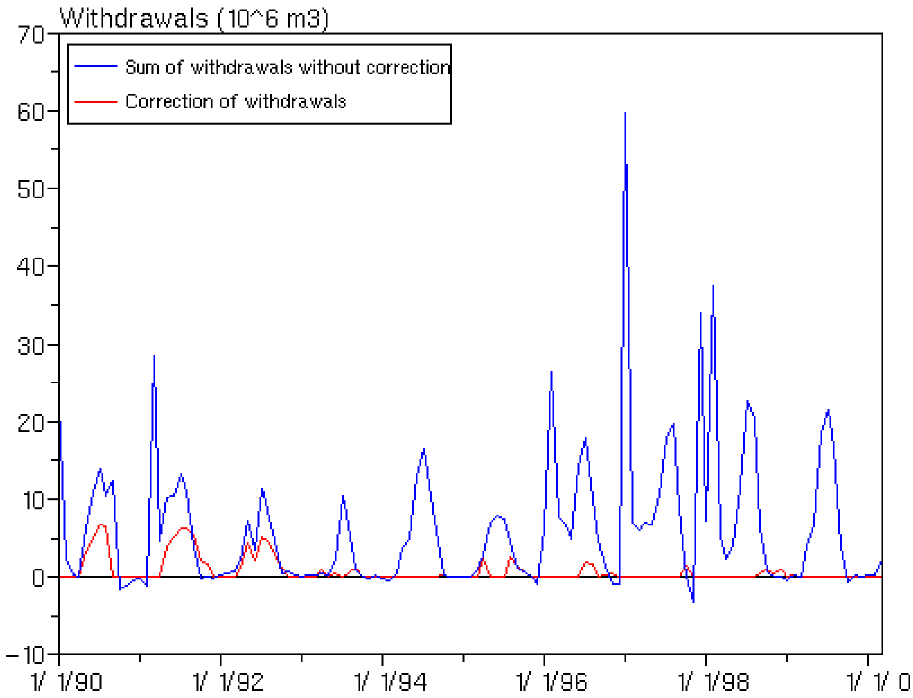


Figure 8: Correction of withdrawals compared with the sum of water withdrawals

Results of the model for the Caia reservoir system

Figure 9 presents the results of the calibration of our model (see Figure 4).

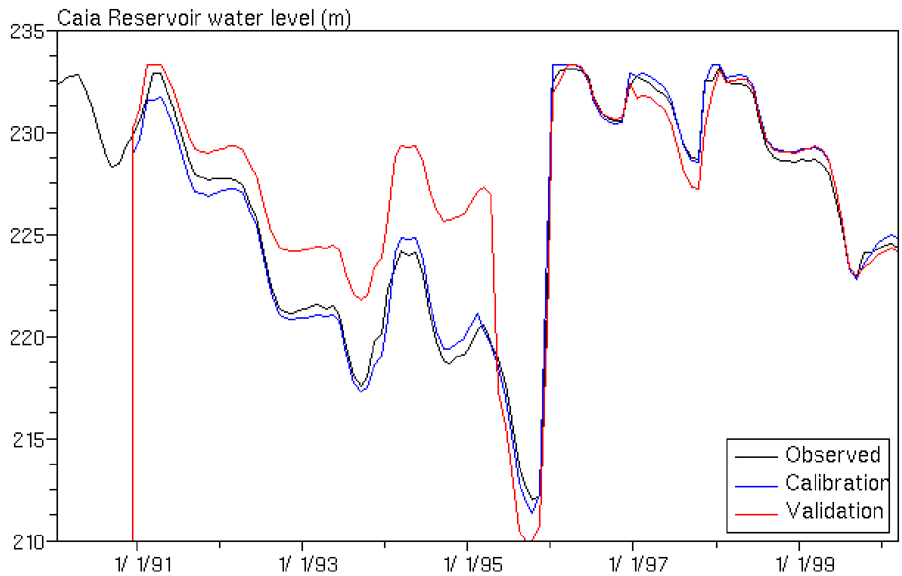


Figure 9: Observed and calculated water levels in Caia reservoir for the years 1990-2000

The calibration is satisfactory with a good match between observed and calculated values particularly for the second period (1995-2000).

In validation mode, the model shows again good performance during the second period (model applied with parameters from the first period) but not on the first (model applied with parameters from the second). Table 9 reveals that parameters from P2 are closer to parameters obtained when using streamflow data (see Table 8).

In spite of the better results obtained with the first set of parameters (calibration on P1), we favour the second set (calibrated on P2). This set is more realistic compared to values obtained with streamflow data. We consider this approach as more robust than the validation on stored volumes due to the correction of water uses introduced in the preceding paragraph.

Table 9: Model parameters for the Caia reservoir system

Period	Size of SMA store	Groundwater losses parameter
P1	354	1
P2	216	0.96

In conclusion the model developed here shows acceptable level of performance to simulate the Caia reservoir water levels and stored volumes. Some uncertainties on water uses remain during the period 1990-1993. The simple GR2M rainfall-runoff model confirms its ability to provide valuable runoff simulation in spite of its limited number of calibrated parameters.

5 Conclusion

The report presents the development of tools to support the management of buffering capacity at the basin scale in a semi-arid catchment.

Two different perceptions of buffering capacity have been highlighted for two different parts of the basin:

- In the Upper part, buffering capacity is oriented towards the long-term management of groundwater resources. Here buffering capacity is defined as the *number of years required to obtain a recovery of wetlands under various economic scenarios*.
- In the Lower part, the same concept is adapted to short or medium term management of surface water reservoirs. Here buffering capacity is *defined each month as the reservoir filling deficit*. This deficit is measured with a synthetic indicator comparable to the Palmer Drought Severity Index (see Palmer, 1965).

Both approaches are supported by the construction of catchment domain models based on two different paradigms:

- For the Upper Guadiana, a qualitative and knowledge based model is proposed (Bayesian belief network),
- For the Lower Guadiana (and more precisely for the Caia reservoir system) a deterministic hydrologic model was built based on the GR2M rainfall runoff model.

The first model is still in a development phase as the interaction with stakeholders just started. The second model provides satisfactory results considering its extreme parsimony.

These tools allow to go a step further in the understanding of buffering capacity management by providing means to calculate the buffering capacity criteria defined previously. The next step is to finalize this calculation through interaction with stakeholders. This will be the objective of deliverable 1.5.5 and 1.5.6.

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