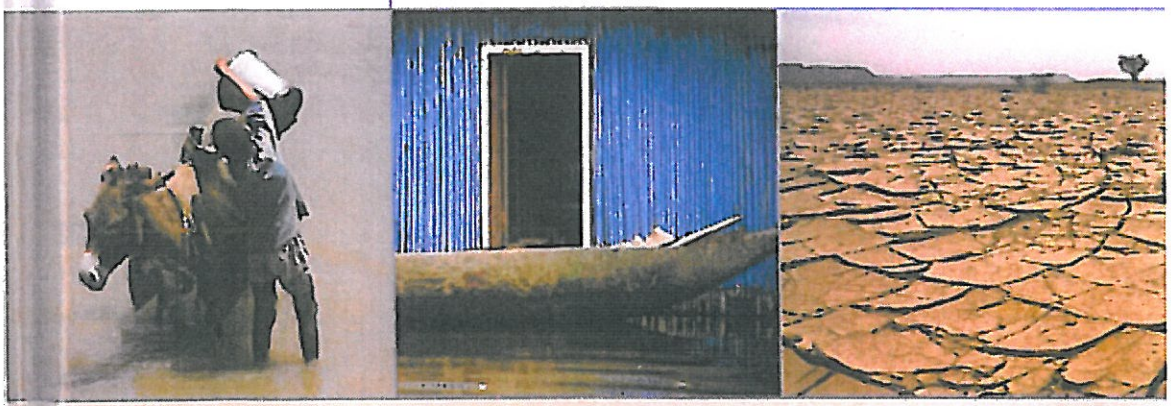
The Adaptive Water Resource Management Handbook



Edited by Jaroslav Mysiak, Hans Jorgen Henrikson, Caroline Sullivan, John Bromley and Claudia Pahl-Wostl

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earthscan
publishing for a sustainable future

London • Sterling, VA

First published by Earthscan in the UK and USA in 2010

ISBN: 978-1-84407-792-2

Typeset by Hands Fotoset, Nottingham, UK
Cover design by Yvonne Booth

For a full list of publications please contact:

Earthscan
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22883 Quicksilver Drive, Sterling, VA 20166-2012, USA

Earthscan publishes in association with the International Institute for Environment and Development

A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data

The adaptive water resource management handbook / edited by Jaroslav Mysiak ... [et al.].
p. cm.
Includes bibliographical references and index.
ISBN 978-1-84407-792-2 (hardback)
1. Water–Distribution–Planning–Handbooks, manuals, etc. 2. Water-supply engineering–Handbooks, manuals, etc. 3. Adaptive natural resource management–Handbooks, manuals, etc. 4. Water resources development–Government policy–Case studies. I. Mysiak, Jaroslav.
TD345.A335 2009
628.1–dc22

2009014036

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This book was printed in the UK by Cromwell Press Group. The paper used is FSC certified and the inks are vegetable based.

6
The Guadiana Basin

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6.1 Background

The Guadiana is a transboundary basin whose water resources are shared by Spain and Portugal. The river rises in the Spanish province of Cuenca and flows 778km first in a westerly direction, then south into the Gulf of Cadiz near the Portuguese port of Vila Real de Santo António (Figure 6.1). It drains an area of 66,800km^2 of which 11,580km^2 (17 per cent) lies in Portugal. Within NeWater, work has concentrated on the Spanish side of the basin, although not exclusively.

Most of the research has focused in the Upper Guadiana Basin (UGB), above the El Vicario reservoir, that provides an example of conflict caused by the over-exploitation of water resources in a semi-arid region. Since the 1970s uncontrolled abstraction of groundwater to provide water for crop irrigation has lowered the water table in places by up to 50m, causing the main river channels to run dry and wetlands to become desiccated. The Tablas de Daimiel National Park, an internationally renowned wetland, is perhaps the most high profile victim of the desiccation process. The abstraction has also supported a booming agricultural economy with all the associated social benefits. The result has been conflict between farmers, local government, regulators and conservationists that legal action, subsidies and engineering solutions have to this date, failed to combat.

To find a solution to these environmental, economic and social problems, the Ministry of the Environment developed a Special Plan for the Upper Guadiana (*Plan Especial del Alto Guadiana* – PEAG). The plan, with a budget of €5500m, was approved by the Spanish Council of Ministers in January 2008.

Source: Guadiana Water Authority (2006)

Figure 6.1 *Map of the Guadiana river basin*

This plan devises a water consumption scenario that is compatible with a mid-term water table recovery (before the year 2027) and identifies water management tools to deal with the Upper Guadiana groundwater crisis. However, the plan does not appear to be in agreement with the principle of full cost recovery required by the EU Water Framework Directive (WFD), and there are many technical and political uncertainties that jeopardize its success.

6.2 Selected themes

Water scarcity

The Upper Guadiana Basin is one of Spain's driest areas. The agricultural sector, which uses 93 per cent of the total, dominates water use; by comparison urban water supply is limited to about 5 per cent and industrial use to 1 per cent (Guadiana Water Authority, 2006). Although agriculture accounts for a high percentage of water use it only contributes 8.4 per cent to Spain's Gross Value

Added (GVA) figure, whereas the industrial sector accounts for 2 per cent. This means that although agricultural water use is 93 times greater than that of industry, the GVA in euros is only four times higher.

The water scarcity problem has been made worse by the increased frequency and intensity of droughts, threatening the livelihood of many local farmers and the economy in general. This has not been a problem because in most cases the supply from groundwater has provided a buffer to the immediate impacts of drought (Hernández-Mora et al, 2003; Garrido et al, 2006). Until now the use of groundwater has continued to virtually negate the effects of the region's endemic drought problems, thus supporting irrigation-based social and economic welfare and acting as the main driver behind the region's prosperity. Uncontrolled intensive pumping by individual farmers has dramatically lowered water tables and has been responsible for considerable negative environmental impacts on groundwater-dependent wetlands, streams and rivers. Most wells in the UGB are currently illegal which makes it difficult to manage water resources in the area.

Recently, increased awareness of water scarcity has led to more thoughtful and sustainable water use. For instance high economic value, water-efficient crops such as olive trees and vines are replacing more water-intensive crops in terms of $m^3\ ha^{-1}$ like alfalfa, maize and sugar beet. Thus the Guadiana basin is slowly moving from a policy of 'more crops and jobs per drop' towards 'more cash and nature per drop'.

Irrigation

Since the 1980's the impact of endemic drought has been offset by the large-scale and uncontrolled abstraction of groundwater used to support an irrigation-based economy, providing prosperity in the region. Policy incentives to intensify agricultural production, low infrastructure costs, and high profitability, have encouraged individual farmers to invest in ground water irrigation systems (Varela-Ortega, 2007). As a direct result, between 1960 and 2003, the area under irrigation increased from 30,000 to 150,000 hectares (Guadiana Water Authority. 2005).[1] During that time groundwater abstraction consistently exceeded $500Mm^3\ yr^{-1}$, exceeding the estimated renewable resource of $230Mm^3\ yr^{-1}$; leading to unexpected and adverse environmental effects. From the 1970s to the 1990s intensive pumping caused the water table to drop by as much as $1m\ yr^{-1}$, and led to the degradation of highly-valued wetland ecosystems including *Las Tablas de Daimiel* National Park, part of the UNESCO and Ramsar-listed *Mancha Humeda* Biosphere Reserve (de la Hera, 2003).

Extensive pollution of groundwater by nitrates through the application of nitrate-rich fertilizers has seriously affected the UGB. In order to comply with the Nitrates Directive a special programme (part of the Common Agricultural Cross-Compliance Policy) to combat the problem has been implemented. Its application has proved to be controversial since farmers maintain that compliance with the Directive leads to a considerable loss of income (Varela-Ortega et al, 2007b).

Since the late 1980s attempts have been made by river basin authorities to establish legal controls on water use. This has included yearly pumping restrictions without economic compensation (also named 'Water Abstraction Plans') and a ban for drilling new wells. The implementation of the 'Water Abstraction Plan' has created ongoing social unrest, hindering Spanish authorities in fully developing the water use limitation policy. Measures co-funded by the European Union (namely the Agri-Environmental Programs) have provided compensatory payments to encourage farmers to voluntarily reduce water use (Varela-Ortega, 2007a). While the latter policy has been more effective, neither measure has met their main objectives. Over 20,000 unauthorized boreholes still exist within the aquifer (Guadiana Water Authority, 2005), and the downward trend of groundwater levels has not been reversed (Varela-Ortega et al, 2008).

Livelihoods and ecosystem services

The EU WFD requires all water bodies to achieve a 'good' status in terms of both quantity and quality by 2015. The main issue in the UGB is how to achieve this whilst ensuring there are no adverse impacts on the social and economic well-being of the area. All stakeholders see this as a difficult task, particularly in view of the area's groundwater management difficulties (Guadiana Water Authority, 2006).

The close connection between ground and surface water in the UGB means that practically all the wetland ecosystems depend on groundwater discharge. To achieve good ecological status groundwater levels in the aquifers need to be raised to near natural levels. Considering this and the socio-economic implications of groundwater recovery, it is unlikely that full restoration of all wetlands can be achieved. The ecosystems located in the central and surrounding parts of the Mancha Occidental aquifer are practically irrecoverable and unless pumping is reduced to practically zero, a series of consecutive wet years follows. However, wetland ecosystems located in other areas of the basin are potentially easier to restore to good ecological status. These wetlands include:

- *Those located along the Cigüela river margins*. These wetland ecosystems were severely damaged by the water diversions made from the Tagus-Segura aqueduct to the Tablas de Daimiel National Park between 1988 and the present day and which are scheduled to continue. The Cigüela river-bed was made deeper and wider in order to facilitate an increased water flow. The volume of diversions from the Tagus-Segura aqueduct to the Tablas de Daimiel National Park were up to 30 million m^3 depending on the climatic conditions at the time. These wetlands face little demand on their resources because the Cigüela is brackish, and not attractive as an irrigation supply. Their recovery should restore the Cigüela river-bed to its natural state.
- *Those located upstream of Peñarroya Reservoir (Ruidera Lagoons)*. The lagoons are fed by the Campo de Montiel groundwater body, which has not been adversely affected by pumping.

Conflict resolution and prevention

Water-related conflicts in the UGB are widespread and have created contention within the main interest groups: conservationists against irrigators; the central government against regional authorities; legal against illegal well owners; and farmers' collectives against each other. These disputes stem from the failure of existing institutional arrangements such as enforced water pumping restrictions and the compulsory creation of water associations. Confrontation has been exacerbated by the hostile relationship between the water authority and water users (Lopez-Gunn, 2003; Lopez-Gunn and Martinez-Cortina, 2006). Many farmers perceive high-level interventions as an attack on their rights to generate a profit, and as a result are unwilling to change their water use practices. In this context, the approval of the PEAG is perhaps the most ambitious and comprehensive attempt to settle water disputes in the region.

NeWater has brought together conflicting stakeholder groups and provided them with the opportunity to express their different views and opinions in an atmosphere of reliability and trust. This has facilitated the understanding and acceptance of the position of others and helped find acceptable solutions.

With regard to transboundary issues, the Guadiana Basin is included in the Albufeira Convention, which covers the protection and sustainable water use in Portuguese-Spanish hydrological basins. The relationship between Spain and Portugal in the framework of this Convention is generally constructive, albeit with rare discord or concern about river flows and water infrastructure developments (Wolf, 2005).

Information management and technical exchange/sharing knowledge

Although adaptive water management is essentially a scientific approach, it emphasises the need for successful public engagement and for an effective social learning process. Apart from recruiting representatives from the most relevant stakeholder groups, NeWater has also targeted a broad cross-section of individuals selected from a number of farmer collectives, since these groups are responsible for 95 per cent of the basin's water use. Primary and secondary educators have also been involved due to their potential 'ripple-effect' in society (Villarroya et al, 2008).

Between 2006 and 2008 Newater met with farmers and educators to help explain the hydrological setting of the Guadiana basin and in particular, the interaction between surface and groundwater bodies and the impact that intensive pumping has had on the wetlands. Meetings began with a background explanation followed by active debates during which the participants proposed practical measures to help implement adaptive water management at the ground level. Field trips were organized in conjunction with each meeting.

The main finding of the meetings was the widespread lack of knowledge about groundwater resources and the impact of over-abstraction on the local environment. Some progress has already been made in the education of the general public through direct contact with decision makers in the Education

Department of the Castilla-La Mancha Regional Government although this is a task beyond the four-year timescale of the NeWater project. These contacts have resulted in the distribution of 500 posters designed by the NeWater team to many state schools in the region. The inclusion of water education in the academic curricula is presently being discussed.

Stakeholder participation process

Conflict, data uncertainty, and concerns over the long-term sustainability of water resources are the hallmarks of the UGB. It requires the development of a long-term sustainable management strategy where every interested sector of the community is given the opportunity to participate in the decision-making process. A stakeholder participation process was established from the outset in which stakeholders were asked to identify the current types of management problems and uncertainties, and the types of tools required to meet them.

Stakeholders were representative of the main collectives responsible for water management at the basin scale,[2] and were selected based on the experience of the research team. The approach attempted to create environment to allow change towards adaptive water management, and to develop site-specific scenarios for the application of adaptive water management tools. A basic premise of the approach to these meetings was the neutrality of the Guadiana research team in order to generate an atmosphere of reliability and trust within which stakeholders felt free to openly share their views.

One of the products requested by stakeholders was developed by the Technical University of Madrid (UPM) and consisted of an agronomic-economic-hydrological framework for analysing policy scenarios and the cost-effectiveness of policy measures. The framework, which links water and agricultural policy, is used to examine the impact of adaptive policy options on socio-economic systems under different scenarios. This methodology is attractive as the selected scenarios are created using input from stakeholders.

The economic model is based on a constraint optimization approach that simulates farmer behaviour and predicts their response to changes in the natural system and adopted policies. Several agricultural and water policy scenarios (stakeholder-driven and policy-driven) have been simulated to assess their impact on different components of the system. Results showed that controlling illegal water mining is a necessary condition for aquifer recovery and should be combined with other actions. Water policies based on Water Abstraction Plan (WAP) quotas lead to important reductions in water consumption at a relatively low public cost, but a high private cost, creating social unrest and opposition from farmers (Varela-Ortega et al, 2007b). Modelling showed that the most cost-effective actions to achieve aquifer sustainability are those based on water pricing. This approach, however, causes income loss to small farms with a less flexible cropping pattern (vineyards) and could threaten their viability (Blanco et al, 2007). The purchase of water rights and the establishment of the water rights market are socially acceptable, but willingness to sell entitled rights varies across farm types and irrigators' attitudes, and is dependent on the offer price,

the types of farm or agricultural systems, and other social factors (age of the farmer, etc.) (Varela-Ortega et al, 2008). Finally, agricultural policies can also promote water savings in some areas when full decoupled or cross-compliance measures are established and thereby contribute to water resource conservation and ecosystem protection as required by the WFD (Varela-Ortega et al, 2007b).

6.3 Groundwater modelling and management scenarios

The Guadiana Water Authority needs to ensure a complete recovery of the aquifer and its associated ecosystems as per WFD requirements. Controversies boil down to establishing the system limits and evaluating potential trade-offs between irrigation water demands and environmental flows. Consultation with Mancha Occidental stakeholders concluded that in this case these issues could be assessed by a numerical groundwater model (Martinez-Santos et al, 2008a).

NeWater has developed a methodology to couple hard-science numerical modelling approaches with the involvement of key water actors (Martinez-Santos et al, 2008b). The main factors controlling the resilience of the system and the drivers for change are identified, while the potential implications for aquifer sustainability are assessed. Full aquifer recovery seems unlikely, while reserves seem sufficient to support current pumping rates in the mid to long term.

Buffering capacity has also been evaluated. This includes the development of a preliminary MIKESHE model of the Upper Guadiana Basin.

6.4 WEAP model

The hydrology model WEAP (Water Evaluator and Planning System) has been specified, calibrated and validated for the Guadiana river basin (Varela et al, 2006). Model output includes monthly simulations of factors such as demand site requirement satisfaction, reservoir and groundwater storage, hydropower generation, evaporation, and transmission losses (SEI, 2008).

This innovative approach of coupling this model with an agro-economic model provides a useful tool for assessing water and agricultural policy-relevant scenarios in water stressed areas (Varela-Ortega et al, 2008).

Both models were run using policy scenarios generated by the scenario building sequence of the WEAP module, taking into account climate and water uncertainties (Varela-Ortega et al, 2007). The WEAP model is able to up-scale the results obtained from the farm-based economic model to the basin level and assess the impacts of the different policies on the aquifer's recharge, the overall availability of water resources and the unsatisfied demand in the basin (Varela-Ortega et al, 2007).

From the results we conclude that short-term water conservation policies implemented in the UGB can help reduce water consumption on farms, but will not be able to secure full recovery of groundwater levels in the Western La

Mancha aquifer. The desired target of aquifer recovery will be achieved when the newly approved measures for reducing water abstractions are fully enforced over the long term; these include measures such as buying water rights and closing unlicensed wells. Even then, recovery will be difficult to meet, during times of extended drought (Varela-Ortega et al, 2008).

6.5 The vulnerability analysis (CART analysis)

The implementation of water allocation limitations faces strong opposition from farmers due to the income loss it causes to them In order to support policy decisions and implementation, it is necessary to analyse farmers' vulnerability to this policy.

Farmers' vulnerability has been considered in economic terms. Input for the vulnerability analysis is obtained from the agro-economic model (Varela et al, 2006) developed by UPM. Two indicators of income loss are used to classify farms into four vulnerability classes: extreme, very high, high, and medium. The two indicators are: (1) the rate of income loss (per cent), and (2) the rate of actual farm income to minimum survival income (per cent), estimated from the official 2007 minimum inter-professional annual wage rate in Spain.

The approach developed by UPM in collaboration with SEI-Oxford highlights the most vulnerable farms. These are obtained using a decision tree tool called CART (Classification and Regression Trees, Salford Systems). The outcome is a classification tree of vulnerable farms, where the classification variables are vulnerability prediction variables. These represent:

1 structural characteristics (farm size, crop diversification, permanent crops and irrigated area);
2 technical characteristics (over abstraction of groundwater); and
3 institutional factors (impact of the degree of implementation of the water conservation policy).

Results show that the WAP provokes substantial farm income loss to all farms, but is higher on small non-diversified farms operating legally and complying with the licensed abstraction rates set by the WAP. Farms are more vulnerable to a reduced enforcement capacity, because illegal boreholes continue to abstract at higher rates placing legal irrigators at a disadvantage.

6.6 Bayesian Belief Networks

One objective of the NeWater project was to translate research outputs into tools for practitioners and end-users to help implement adaptive and integrated water resources management. One of the tools chosen was based on the application of Bayesian Belief Networks (BBNs) (Bromley, 2005; Henriksen et al, 2007). This aided water management decision making, stakeholder engage-

ment, and identification of management potentials and constraints. A BBN is a decision support system based on Bayes' rule of probability. The nature of the technique enables identification of gaps in data or knowledge in the system, leading to an inability to meet some of the goals of the WFD.

Two BBNs have been developed for the UGB. One at a regional scale covering the entire UGB, the other at farm scale (Zorrilla et al, 2007). The regional network is designed to investigate hydrological, social and economic impacts of the PEAG at the scale of the Mancha Occidental Aquifer. In contrast, the farm scale network concentrates on the impact of the plan at single farm level. Results show that with the full implementation of the Special Plan, there is a 40–75 per cent chance of aquifer recovery before 2027 (deadline established by the WFD). However, full implementation of the plan will lead to a certain reduction of current agrarian economic production, which may be important for small vineyard farms.

6.7 Water Footprint

As the most arid country in the European Union, water use and management in Spain is a hot political and social topic. Knowledge of virtual water, defined as the volume of water used in the production of a commodity, good or service, and the water footprint (water volume used to produce the goods and services consumed by a person or community) together with an economic analysis, can contribute to improved adaptive management and allocation of water resources. Furthermore, this analysis could provide a multidisciplinary framework for achieving WFD objectives (Aldaya et al, 2008).

The present study deals with the economic and hydrological analysis of the virtual water and the water footprint of the Guadiana river basin, taking into account both green and blue (ground and surface) water (Aldaya and Llamas, in press). In the Guadiana basin the main water consuming sector is agriculture (about 95 per cent of total consumption). Within this sector, high virtual-water and low-economic value crops are widespread in the Upper and Middle Guadiana regions. The economic productivity of blue water ranges between 0.1–0.2 €/m^3 for low cost cereals and 1.5–4.5 €/m^3 for vegetables in the Upper and Middle Guadiana basin. In contrast, the value for vegetables can amount to 15 €/m^3 in the Lower Guadiana and TOP domain (group of three small river basins – Tinto, Odiel and Piedras – located near the Guadiana River mouth). Nevertheless, factors such as risk diversification, labour or other environmental, social, economic and agronomic reasons have to be taken into account in order to find a balance. The major environmental challenge to agriculture is the preservation of the environment without damaging the agricultural sector economy. The Guadiana basin has already moved in the direction of 'more crops and jobs per drop'. The aim now could be to move towards a policy of 'more cash and nature per drop', particularly in the Upper and Middle Guadiana basin.

6.7 The future

The ongoing water management problems in the Guadiana basin, particularly the upper Guadiana, mean that the goals set by the WFD are unlikely to be achieved within the required timescale.

The continued lack of transparency concerning land use and water rights in the Guadiana needs to be resolved and management policy requires full disclosure and a clear definition of these rights. In addition the recently approved Special Plan for the Upper Guadiana does not conform to the principle of full cost recovery specifically required by the EU WFD. Moreover the €5500m budget to implement the Plan is unlikely to be made available in the near future, meaning that any significant short-term progress is doubtful.

Since the emphasis of the WFD is to improve the ecological status of the environment, it is important to consider the long-term impact of water management practices in ecological terms. The prospects of achieving full recovery of groundwater levels and complete restoration of associated wetlands are extremely low mainly due to political and economic issues. Given the severity and complex nature of the problem it is possible that the Spanish Ministry for the Environment will request an extension of the deadline for achieving the environmental objective, or even an exception.

The detailed economic studies of the agricultural sector of the region undertaken by NeWater have provided an objective in-depth examination of the situation. We consider BBNs to be a particularly effective and easy technique to engage stakeholders and assist decision making under conditions of uncertainty. Application of the methodology to all Spanish basins should be encouraged in order to facilitate participation as required by the WFD. To encourage the application of BBNs a 'Train the Practitioners' workshop was organized to help disseminate the technique among Spanish practitioners.

Finally, we believe that the 'Water Footprint' analysis, combining hydrological and economic data, will prove to be a valuable aid to transfer from a policy of 'more crops and jobs per drop' towards 'more cash and nature per drop' and will ultimately benefit water governance in all industrialized semi-arid countries.

Notes

1 It is worth noting that no reliable figures for annual water abstraction from the aquifer exist; neither is there an estimate of the total surface area under irrigation, nor of the distribution of irrigated crops (Guadiana Water Authority 2006).
2 Stakeholders included: the Guadiana River Basin Authority (Confederación Hidrográfica del Guadiana), the regional agricultural authority (Consejería de Agricultura de Castilla-La Mancha), various farmer collectives, groundwater user associations and local and national environmental associations.

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