4

CHAPTER

Assessing the first cycle of the Water Framework Directive

The enforcement of the WFD in Spain was initiated in 2003. The first RBMPs had to be released by 2009, implemented during the next six years and assessed by 2015 against progress towards achieving EO. Building on the outcomes of that evaluation, the second plan 2015-21 would be elaborated.

In the Andalusian Mediterranean RBD, the draft documents of the RBMP 2009-15 were released for public consultation in 2010. During the next year, the formal participatory process was arranged at the scale of the whole Almeria province (containing four and a half basins). In addition to the comments to the draft plan, one workshop with farmers, another with representatives of all types of users, and a third one focused on e-flows negotiation, were arranged by the RBD (Ballester and Espluga 2012). Adding to this endeavors, the ALTAGUAX project enabled stakeholders from the Andarax basin to develop their own participatory diagnosis of water problems, and to propose courses of action (Van Cauwenbergh et al. 2008, Van Cauwenbergh and Ballester 2015). The final RBMP 2009-15 was endorsed in 2012 with hardly three years for executing the program of measures until the draft of the new RBMP 2015-21 was opened to consultation at the beginning of 2015. Van Cauwenbergh and Ballester (2015) evaluate the relation between the institutional and the project processes, pinpointing the factors that hampered a more effective implementation of the ALTAGUAX outcomes. According to the authors, the most relevant factor was the lack of real political commitment and of mandate of the water administration over budget allocations. They identified the following research challenges for the Andarax: 1) To improve the discussion on policy outcomes (reflected in the PoM of the RBMP); 2) to create mechanisms aimed at monitoring and evaluating the extent of the implementation of stakeholders′ preferences, and the effectiveness of the implementation of those decisions.

The objective of this chapter is to assess the implementation of the first cycle of the WFD in the Andarax basin. This is undertaken on a twofold basis: First, through the evolution of narratives during the planning process, and second, through the evolution of societal metabolism of water. For this purpose, I build on the concept of semiotic process of water management described in section 1.2.3, attending to the following questions: Which are the main narratives about water management in the Andarax basin? Which are the main conflicts and coalitions amongst these narratives? Which are the dominant narratives in the RBMP 2009-15? How did societal metabolism evolve during the first cycle of the WFD? Did the actions implemented respond to the perceived problems by stakeholders? Did they contribute to achieve policy goals? How did the RBMP perform in terms of discursive closure, social accommodation and problem closure?

4.1. Methods

This chapter focusses on discourse analysis as main analytical tool to identify non-equivalent narratives[30]. This is combined with a diachronic analysis of societal funds and water use during the management period in order to appraise its outcomes.

Discourse analysis

The definition of narratives or story-lines typifying perspectives over water management was undertaken through discourse analysis. Four documents produced during the ALTAGUAX workshops, another four from the RBMP 2009-15 and the draft memory for the RBMP 2015-20 were reviewed (Table 4.1). In order to code the text, a flexible top-down procedure was followed, departing from three defined common contrasting perspectives about water management, at the time paying attention to other knowledge claims that did not fit into the pre-defined categories. These three prior narratives were supply-side, demand-side and deep ecology. Throughout the analysis, another two narratives emerged as relevant: rural livelihood and knowledge and governance. Codes were extracted and classified in a matrix according to two criteria: i) type of narratives and ii) problems vs course of action. Codes consisted on whole knowledge claims, sentences with specific identifiable meaning. The two first ALTAGUAX documents enabled narratives identification on a general basis, while the documents from workshop 4 enabled a geographical distribution of these narratives.

Because the objective of the workshops was to create consensus information about water management issues, workshops facilitators merged the different perceptions into inclusive statements. Stakeholders denounced ambiguity in the measures proposed in the RBMP. Ambiguous concepts are often used as a discursive strategy in order to gather consensus over grand objectives, like recover aquifer health, even though different actors may disagree on the motivation for reaching a certain goal or on the means to be used. Therefore, apparent coalitions among actors have to be carefully analyzed in order to identify possible ambiguities and distinguish them from actual consensus. In this context, the coding of the text in terms of definition of the problem

[30] Zora Kovacic has coauthored the discourse analysis in this chapter.

and course of action proves very useful in shedding light over recurrent concepts and issues.

Table 4.1 *- Documents reviewed for discourse analysis*

Document	Date	Contents	Analytical objective
Altaguax Workshop 1 minutes	2009	Water management problem diagnosis	Categorize and characterize narratives
Altaguax Workshop 2 minutes	2009	Proposal of management measures to solve problems	
Altaguax Workshop 4 preliminary document	2010	Problem diagnose and program of measures for each water body in the RBMP draft	Identify contrasting narratives; spatialize dominant narratives
Altaguax Workshop 4 minutes	2010	Allegations to the RBMP draft per water body	
RBMP 2009-2015 draft program of measures	2010	List of measures classified per type and other attributes	Pinpoint dominant narratives
RBMP 2009-2015 final program of measures[31]	2012	Same than draft but with required budget in total and until 2015	
Appendix XI.3. Report on allegations to the draft RBMP 2009-2015	2012	Answer to allegations from ALTAGUAX workshop 4. New PoM	
RBMP 2015-21 draft program of measures[32]	2015	List of measures classified per type and budget until 2021	

In order to pinpoint dominant narratives, the draft documents of the RBMP 2009-15, the answers from the Andalusian Water Agency to the comments presented by ALTAGUAX stakeholders, and the PoM in both the draft and final RBMP 2009-15, as well as the

[31] Demarcación Hidrográfica de las Cuencas Mediterráneas Andaluzas. Documentos plan hidrológico de la demarcación hidrográfica de las cuencas mediterráneas andaluzas, periodo 2009-2015 http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.7e1cf46ddf59bb227a9ebe205510e1ca/?vgnextoid=6d3173f2c746a310VgnVCM2000000624e50aRCRD&vgnextchannel=0bb66af68bb96310VgnVCM1000001325e50aRCRD

[32] Planificación Hidrológica 2016-2021 http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.7e1cf46ddf59bb227a9ebe205510e1ca/?vgnextoid=4b90cfa0d2f0f310VgnVCM1000001325e50aRCRD&vgnextchannel=fd0f122f4df3f310VgnVCM2000000624e50aRCRD

draft RBMP 2015-21 draft, were reviewed. The analysis of the answers to the allegations of stakeholders, and the measures proposed in the final RBMP, sheds light about the extent to which comments from stakeholders influenced final decision-making and which narratives pervaded those decisions.

Interviews, field observations and focus group

Nine semi-structured interviews to key stakeholders were undertaken during April-May 2014 (Table 4.2). The purpose of the interviews was to update water problems defined in 2009. Interviewees were asked to give their opinion on whether each of the problems identified in 2009 had been solved, were being solved, remained the same or were worsening.

In addition, a focus group was organized in May 2014 with the aim of developing an exercise of multi-criteria evaluation of water management alternatives and of discussing the implementation of the RBMP. Main results from this workshop are gathered in Appendix 3.

Table 4.2 *- Stakeholders interviewed*

Stakeholder type	Area	Gender
Mayor from a rural municipality	Nacimiento	Woman
Representative from traditional irrigation community	Alto Andarax	Man
Organic farmer	Alto Andarax	Woman
Environmentalist, independent consultant on cultural heritage	Bajo and Alto Andarax	Man
Representative from agriculture administration	Alto Andarax, Nacimiento and Tabernas	Woman
Representative from intensive greenhouse farming irrigation community	Bajo Andarax	Man
Representative from Almeria province administration responsible for urban water supply	ALL	Men
Representative from the Andalusian Mediterranean Hydrological District in Almeria province	ALL	Men

Grammar

The water metabolism was updated with the information from the new RBMP 2016-21 draft, using the same grammar than the previous Chapter 3, and visualizing it in a similar dendrogram for comparative purposes. In addition, a multi-level accounting of human activity was calculated for 2001 and 2011 (dates of the Spanish National Census, latest in 2011 http://www.ine.es/censos2011_datos/cen11_datos_inicio.htm), as well as of land uses for 2005 and 2011 (from the Spanish Land Occupation Information System http://www.juntadeandalucia.es/medioambiente/site/rediam/menuitem.04dc44281e5d53cf8ca78ca731525ea0/?vgnextoid=ca74d2aa40504210VgnVCM1000001325e50aRCRD&vgnextchannel=7b3ba7215670f210VgnVCM1000001325e50aRCRD&vgnextfmt=rediam).

4.2. Results

Water management narratives

Five different narratives on water management have been identified through knowledge claims regarding the perception of problems and the proposed course of action (Table 4.3). In what follows, a general characterization of the narratives is presented including their broad construction of water scarcity (as a concept that invokes 'the essence' of water problems in semi-arid areas), their main underlying assumptions, their scale of observation and their type of story-tellers in the Andarax basin.

Supply-side management: this narrative deems water scarcity as a technical problem and its underlying assumption is that increasing demands can, and shall, be attended through new technologies and infrastructures. It focusses on the level of the whole society (*s*) by considering the total water demand (not specific uses) to be met by introducing more resources in the system as a whole, disregarding internal metabolism (society is treated as a black box). Story-tellers of this narrative are the traditional epistemic community of the hydraulic paradigm that includes engineers from water utilities and desalination plants, large agricultural lobbies and mayors with expectations of incrementing urban development.

Demand-side management: this second narrative acknowledges water scarcity as a problem of excessive water demand (we use more than what is available), and proposed solutions orbit around measures to control its expansion, mainly through economic instruments and increasing efficiency. The narrative is based on a low scale of analysis, associated with individual water users (*s-x*). The focus is on the consumers of water and proposed courses of action build on the assumption that water savings at individual level lead to a reduction of the overall water demand. Story-tellers of this narrative are typically advocates of IWRM that shift from supply to demand-oriented perspectives, that in the case of the Andarax groups together different coalitions depending on specific problems and measures as will be discuss in next section.

Deep ecology: this narrative follows an ecosystem integrity perspective. It considers that water scarcity is human-induced and that the conservation of ecosystems should be a constraint over human activities. It focusses on the contexts (*e+x*), on ecosystem metabolism and the water cycle, and management measures are twofold: on one hand, they emphasize the need for adapting/reducing the size of human activities to the limits imposed by ecosystem conservation and renewability of resources; on the other hand, they claim for ecosystem restoration to a purportedly pristine ecological status. This is based on the premises that the thresholds of ecosystem integrity can actually be predicted by models within an accepted interval of confidence and that human systems can adapt to 'live with less'. Story-tellers are environmental groups and other advocates of the WFD environmental objectives fulfillment, amongst them some of the managers and technicians from the Andalusian water administration.

Rural livelihood: this is the narrative of rural communities, their mayors, traditional farmers and irrigation communities, and rural development groups. It has a social-ecological metabolism perspective; the level of analysis is the whole community but with a focus on its practices linked to the perception of water as part of their identity (*s/e*). They do not perceive water scarcity as a problem since they consider themselves adapted to their context. Courses of action claim for integrative policies that support the maintenance of the community in their territory, battling against rural exodus and conserving heritage and traditional practices.

Knowledge and governance: this narrative deems water scarcity as a governance problem. Existing institutions are incapable of dealing with water problems because they are considered culturally obsolete according to the challenges of the WFD. It focuses on the information side of the hydro-social system and courses of action are related to the improvement of information and knowledge, and the need for institutional reforms seeking better adaptive management structures. Story-tellers include most stakeholders that are not decision-makers from the RBD, but special emphasis is posed by the advocates for the New Water Culture narrative.

Table 4.3- *Claims from water management narratives in the Andarax River basin*

Claims	Supply-side	Demand-side	Deep ecology	Rural livelihood	Knowledge & Governance
Problems	Insufficient resources to satisfy increasing demands; aquifers overdraft and untreated wastewater discharges				
	- Decrease on available run-off due to excessive upstream withdrawals - Insufficient quantity and quality of water - Insufficient production of water through reclamation and desalination - Desalination plants are under-exploited - Insufficient regulation of surface water bodies	- Lack of awareness to save water - Obsolescence of supply infrastructures - Irrigation needs to be modernized with more efficient systems - Real water costs are not paid - Nobody wants to raise water tariffs because it entails a political cost	- Inter-basin transfers increment vulnerability to drought - Natural springs and dependent ecosystem are drying out due to water table decrease - Biodiversity loss (birds) - Reforestation projects do not take into account contextual ecological constraints - Pollution problem due to pesticides and fertilizers use in intensive agriculture - Untreated wastewater discharges is causing severe habitat deterioration - Desalination plants increment aquifer salinization and brine impacts marine ecosystems	- Desertification and erosion due to abandonment of agriculture and terraces - Water scarcity is new in upper basin, water used to be abundant thanks to traditional infrastructures like mines and *acequias* - Vulnerability to drought - Agriculture is not economically viable anymore, facing continuous productivity decrease - Ageing population, youth people are moving to urban areas - Fountains are drying - Untreated wastewater discharges are a source of conflicts - Insufficient support to traditional agriculture - Not clearing the riverbed increases vulnerability to floods	- Lack of monitoring and control over illegal extractions - Insufficient knowledge about aquifers functioning - Insufficient data and information used in decision-making - Lack of transparency, lack of access to the required data for public participation - Lack of coordination between different administrations (water, land use, agriculture), information is not shared neither reused - Insufficient justification of goals and deadlines. Cost-effectiveness of measures decided without scientific evidence. Ambiguity - Lack of drought emergency plans - Political use of water - We don't need more infrastructures but better governance

Claims	Supply-side	Demand-side	Deep ecology	Rural livelihood	Knowledge & Governance
Courses of action	- New desalination and wastewater reclamation plants. Increment capacity of current plants - Build new dams and increment current ones - Inter-basin transfers from groundwater dwells - Refill aquifers with wastewater to increase availability - Rainwater harvesting - Diversify water sources and adjust water quality to end use	- Irrigation efficiency improvement - Full water services costs recovery, raising water tariffs, including environmental costs of aquifers overdraft - Improving efficiency of the urban supply by renewing infrastructure and better maintenance - Awareness-raising campaigns	- Adapt water demand to natural water availability. Limit growth, especially of agriculture - Implementation of environmental flows on regulated rivers and extractions for irrigation - Cross-compliance for agricultural subsidies Promote conversion to organic farming - Protect high-value ecosystems - Hydro-morphological restoration. Improve river connectivity - Soft not hard infrastructures are needed - Reforestation of abandoned agricultural lands - Improve wastewater treatment plant - Do not increase desalination until impacts over aquifers are known and controlled	- Economic support to rain-fed crops like olives, almonds and vineyards and organic farming - Maintain traditional irrigation infrastructures and farming practices as a form to prevent erosion - Develop new types of economic activities within the Natural Park - Natural recharge through traditional irrigation practices for aquifers recovery - River bed cleaning according to protocol of good practices	- Monitor withdrawals and ecosystem quality. Improve data for management - Improve knowledge and management of aquifers - Control over illegal extractions, and wastewater discharges - Better administrative efficiency on water rights procedures - Application of law on Transparency and Access to Environmental Information - New governance structures at both supra-municipal level (for urban supply and wastewater treatment) and river basin level (for different uses coordination), combining public and private entities - Integrated water and land planning - Grand Social Agreement to not politicize water

The narratives have been typified in the belief that they may be applicable to similar contexts along the Mediterranean. The first three narratives (supply-side, demand-side and deep ecology) are common contested perceptions about water issues in semi-arid areas with intensive agriculture in competence with urban growth for limited and degraded water resources (Del Moral et al. 2007). The rural livelihood narrative is important in river basins containing both rural and urban systems and/or where traditional agriculture is being replaced by intensive practices, like the Upper Andarax. The knowledge and governance narrative is particularly relevant in Spain where multiple citizen networks follow the implementation of the WFD and participate in planning processes. These groups develop an active quality control over the information used for decision-making (Hernandez-Mora et al. 2015). Next section discusses the specificities of how these narratives appear in the Andarax case, how do they hybridize or oppose and which are the narratives permeating the final decisions, thus becoming dominant.

Narrating 2009

There is an overall agreement amongst Andarax stakeholders in that water resources are insufficient to attend current and future water demands, and in that aquifers are overexploited either in quantity or in quality. However, perceptions around the causes of the problem (detailed diagnosis) and the effective course of action in order to face these challenges greatly diverge. It is generally assumed that water demand would increase with economic growth, and therefore this is an *a-priori* belief from which many claims are stated. Another consensual problem was the pollution along the river caused by untreated wastewater discharges due to the lack of maintenance of collectors and treatment plants. It appears in claims associated to all types of narratives: as a social drama, as a cause for habitat degradation, as the need for more reclaimed water, as the capacity to refill aquifers and as an institutional failure.

The governance and knowledge claims dominate the problem structuring indicating that the information used for the draft RBMP was not considered valid by stakeholders. Proposals go in the direction of refining information and access to it on one side, and of renovating institutional functioning on the other. The course of action that received the most support in a voting exercise was "improving knowledge and management of aquifers overexploitation". This is a consensus that links improved scientific knowledge to better decision-making and management. On the other hand, enhancing the agility of the water administration in processing water rights, a better coordination with other public administrations, and an effective monitoring of withdrawals are important repetitive claims. An interesting statement is the claim for "avoiding *politization* of water management", referring to the intentional use of water problems rhetoric by political leaders for gaining clout. It came from water managers and received a lot of votes in the ranking exercise. This uncovers a perception that water problems can be technically handled through better knowledge but should not be used with political or electoral purposes.

The rural livelihood narrative states itself in opposition to the supply-side narrative of large agricultural lobbies from intensive systems in downstream areas ("we have nothing to do with them"). It is the second largest list of problem claims of the five narratives, including structural problems like population ageing, agricultural abandonment and erosion, discussed in Chapter 2. Certain tension is observed with the installation of new water-intensive farms in their communities in what regards the future of rain-fed crops and of traditional irrigation systems. In addition, traditional farmers have a conflict with the deep ecology claim for legally binding ecosystem requirements of water because they perceive themselves as part of the ecosystem to be maintained. The efficiency argument from the demand-side narrative is very persuasive in solving this conflict, because it is defended as a win-win for both the river and farmers. A second conflict comes in hand of the perception of mayors about an increased vulnerability to floods due to the lack of clearance of the river-bed, what the RBD representatives accused to the ecological quality mandates of the WFD. Courses of action within the rural livelihood narrative include protection and support of traditional farming systems and rain-fed crops, and diversification of economic activities taking advantage of the Sierra Nevada Park.

Deep ecology problems gather together pressures and impacts detected by decision makers in the draft RBMP, plus some others denounced by stakeholders like unsuccessful reforestations or the impact of brine from desalination plants. The course of action with more proposals is found within this narrative, what is expected insofar as they pursue the ecological quality policy goals. These measures are twofold: on one side there are actions aimed at ecosystem restoration as a strategy to achieve the good status, defended by the technical staff from the RBD; on the other hand, there are measures claiming for an eco-integration of human activities within natural resources renewability boundaries, defended by environmental groups.

Supply-side problems refer to the insufficiency of resources to attend demands, and the need for new technologies (wastewater reclamation, desalination) and infrastructures (dams and regulation) to increment water availability. These claims were not so abundant but their advocates are in very influential positions. An innovative claim from this narrative is a better management of water quality allocation so that each end use receives water with appropriate quality but not better than required. Soft proposals for incrementing water supply are rainwater harvesting and aquifer recharge with wastewater.

Finally, demand-side problems gather together advocates for efficiency improvement, which are closer to the supply-side, and those for awareness raising and pricing as instruments for controlling demand, which are closer to the deep ecology perception. This coalition reveals that the ambiguity of demand-side arguments, core in IWRM, enables different interpretations, working as a consensual-boundary strategy. The problem is that the aggregation of changes produced at individual level may lead to different emerging outcomes depending on how those changes are managed. The Jevons paradox tells us that savings at the individual level result in spare capacity at the higher level, which in turn increases overall consumption in the long run. In the case of irrigation technical efficiency, the rebound effect has been explained by the lack of a parallel reduction of water rights, as well as by the lack of effective monitoring and planning of withdrawals and uses (Sampedro and del Moral 2014, Berbel et al. 2015). If volumes granted by water rights are not diminished and actual consumptions are not controlled, users reuse the 'saved' water in something else for their own profit. A strong opposition to this coalition comes from the knowledge and governance narrative. As stated by an actor "there are no legal guarantees of what to do with water savings, they are just used in the water administration creative accounting to close balances". In other words, there is no strategy at upper levels to manage what happens at lower levels so that the outcome is the one expected. In the case of the Andarax, the underlying reason is that the RBD deems efficiency as a strategy to meet agricultural demands (a supply-side measure) and not to reduce demand. However, the discourse around efficiency in planning documents is ambiguous enough to induce its interpretation as a demand-control or even as a deep ecology measure.

It is noteworthy to mention that there is a current observed trend in multiple cities in Spain towards a decrease in urban water demand, both in absolute and relative terms, as a result of the reduction of households' consumption (Sampedro and del Moral 2014, March et al. 2014). However, this is explained by the effectiveness of awareness-raising campaigns, usually during drought events. Finally, thorough studies around pricing mechanisms in agriculture reveal great uncertainty around the elasticity of water demand, and around its actual effectiveness as a conservation measure, depending on a variety other factors (Venot et al. 2007, Molle 2008b). As declared by stakeholders, raising water tariffs is extremely unpopular in Spain and usually triggers social protests both in agriculture and urban end users.

Dominant narratives 2012

Table 4.4 presents the dominant narratives observed in the final RBMP 09-15, in what regards the main courses of action foreseen for the main water bodies in each WHS, and the opposed alternative narratives from stakeholders. It is important to clarify that all stakeholders have a homogenous position; indeed some of them supported the proposals of the RBD, or even went further proposing measures within the same narrative. My aim is to show that there were at least some contrasting narratives in the different areas. From all the measures proposed by stakeholders in the comments, those positively responded and included in the RBMP were: the increment of irrigation and urban supply efficiency, the improvement of wastewater treatment and augmentation of the reclamation capacity, and the creation of supra-municipal institutions for management of wastewater treatment plants. The improved knowledge proposals were partially incorporated in 38 programs devoted to enrich data and information for the whole RBD, and to create new management communities for aquifers. The deep ecology measures included in the plan were, as expected, those dealing with ecosystem restoration. On the other hand, the proposals from the rural livelihood narrative were rejected considered "out of the scope of water planning" (RBMP 2009-15, Appendix XI.3, p. 193). Attending these petitions would require a better coordination amongst several public administrations, and the integration of land and water planning, proposals that were also deemed beyond the responsibility of the RBMP (p. 245).

The budget for the PoM is shown in Table 4.5, split in typologies according to the RBMP. It can be observed that the measures related to knowledge and governance and ecosystem restoration counted with the lowest shares in the RBMP 2009-15. Pollution control was in the third position, with funds mainly allocated to the improvement of wastewater treatment. There was not any measure of actual water demand management, since water prices were not raised, and efficiency was considered a supply-side measure in the RBMP. On the other hand, 84% of the funds were allocated to nine supply-side measures including desalination, more surface water regulation, reclamation and efficiency of urban supply and of irrigation (this latter receiving up to 38 M€ from the rural development funds from the CAGP as explained in Chapter 3).

Table 4.4- *Contrasting narratives in different WHS*

WHS	Dominant narratives	Alternative narratives
Bajo Andarax	Supply-side	Knowledge & governance and deep ecology
Alto Andarax	Demand-side and deep ecology	Rural livelihood
Nacimiento	Supply-side and demand-side	Rural livelihood
Tabernas	Supply-side and knowledge & governance	Knowledge & governance and deep ecology

Table 4.5 - *Number of measures and budget for each RBMP horizon. Source: RBMPs 09-15 and 16-20*

	RBMP 2009-2015		RBMP 2016-2021	
	nº measures for 2015/total	Budget 2015 **(€)**	nº measures for 2021/total	Budget 2021 **(€)**
Supply augmentation	4/5	85.700.000	2/3	13.575.000
Efficiency improvement	5/5	50.695.000*	0/2	14.332.394*
Pollution control	4/8	14.899.000	2/9	5.668.000
Ecosystem restoration	3/4	3.227.000	1/4	2.658.500
Knowledge & governance	34/38	6.026.945*	11/34	4.065.075*

* Proportional share of the RBD budget for the Andarax

Narrating 2014

In spring 2014, interviewed stakeholders considered the problem diagnosis of 2009 still valid with some minor changes. Table 5.6 shows in columns the number of interviewees that agreed with the one of the current situation of the problems identified in 2009. In general, their opinion on the RBMP operation was very poor because almost none of the foreseen measures had been executed and those implemented either faced barriers or were simply ineffective. A prominent example is that institutions for collective management of wastewater treatment plants had been created but municipalities did not provide sufficient funding for their maintenance, thus they were not operative. There is a conflict between local and regional administrations regarding the new tax imposed by the Andalusian Water Law to urban users in order to fund wastewater treatment. This money is defended by the regional government for funding the construction of new infrastructures, whereas mayors in the Andarax claim it for maintaining current operation costs. The lack of transparency of the Andalusian administration about the destiny of these funds intensifies the dispute.

***Table 4.6** - Water management problems 2014*

Problem	Worse	Same	Solving	Solved
Current and future demands satisfaction		9		
Insufficient surface water flows	1	6	2	
Aquifer overdraft & marine intrusion		9		
Nitrates & pesticides pollution		5		2
Wastewater pollution. Lack of maintenance of wastewater treatment plants	2 (Bajo)	1(Alto)	3	1 (Nac)
Ecosystem degradation		5		1
River bank alteration and instability	1	6		
Desertification and erosion	2	7		
Vulnerability to floods	1	8		
Vulnerability to droughts		9		
Lack of coordination amongst administrations	1	6		
Integration of land and water planning	1 (Reg)	5	2 (Local)	
Lack of control over withdrawals		9		
Insufficient access to information		7		

Regarding the shortage of surface flows, two stakeholders claimed that once the process of change to drip irrigation had finished, environmental flows could be attended. On the other hand, two other stakeholders considered that this on-going process of technical shift was already triggering the abandonment of some *acequias* and *galerias* with a negative tradeoff on aquifer recharge and dependent vegetation. In the Upper Andarax, some agricultural modernization projects had been rejected because small farmers with low productive systems were unable to cover the 10-20% share of unsubsidized costs. Furthermore, they perceived the situation with agricultural land abandonment and erosion of agricultural terraces in the area and in Nacimiento as worsening. However, none of the reforestation or ecosystem restoration projects had been executed in order to retrieve this process.

Comprehensive land plans had been developed in the previous years at municipal level and were about to be endorsed, what is a step forward in the integration of land and water planning. However, at the level of the Andalusian administration that is responsible for regional planning, no progress was perceived in regards to agricultural areas expansion and to control or at least regularization of unauthorized wells. According to the RBD representative, an important attempt to join agricultural and environmental public administrations had failed due to an excessive bureaucratic burden. The issue of data and transparency was one of the most problematic for the interviewees. Collected data is not released afterwards, and the available information does not reach water users. Small farming organizations and minor groups are not invited to decision-making tables, neither are the mayors from small municipalities. The RBD representative argued that there is a problem of sufficient data to make it available to the public. Authorized wells were installing accounting devices but the RBD had no capacity to monitor them, and those in unauthorized pumping situation were directly out of the water balance. There was a general mistrust to the regional water administration, which was perceived as opaque and working for big economic interests "…after the crisis the established logic is that of anything for profit is good".

The economic recession was precisely the main explanation given by the RBD representative acknowledging these deficiencies in the plan implementation. The water administration in Andalusia has gone through continuous reforms during the decade, in a context of intense socio-political changes and tensions between the central and the regional governments. The main battle between them regarded the competences over management of Guadalquivir River basin, finally won by the central administration. As a result, the budget allocated to the maintenance of the water administration in Andalusia was substantially waned, as well as its competences and power to make decisions. Only those measures getting external funding (irrigation efficiency and augmentation of reclamation capacity in Almeria wastewater treatment plant) were being executed in spring 2014. On the other hand, the transfer of desalinated water was stalled because of the farmers' rejection to pay for its costs.

Becoming 2015

The draft of the new RBMP 2016-20 is almost an update of the previous one and the PoM remains nearly the same (Table 4.5). However, it counts with a significantly less ambitious budget, barely 25% of the previous one. Regarding progress towards policy goals, there was no formal evaluation of the achievements of the previous PoM. However, the assessment of the status of water bodies was updated. In this sense, some small but relevant changes are observed: the aquifer in the area of Nacimiento is now considered good status, whereas the one in Sierra de Filabres is deemed in bad status and its EO is deferred to 2021. It is noteworthy that these changes are due to an improvement of the available information through several monitoring campaigns in 2012-2014 but not to changes induced by the implementation of the RBMP. The rest of aquifers did not change their assessment. In regards to surface water bodies, the horizon for good status achievement in the Upper Andarax is deferred to 2021, whereas all the rest are set for 2027, including those that previously had been previously assigned LSO.

Table 4.7 presents a multi-level accounting of land uses and human activity. Although land covers are not included in the table, a notable change is that all types of vegetation covers slightly diminished their area from 2005 to 2011 (less than -2% on average), with the only exception of *Quercus* sp. forest that grew in 7%. Overall direct land occupation increased in 3.5% between the two dates, a total of 1,569 has. This expansion was mainly driven by urban development (+9% of expansion in residential areas, +53% in leisure areas, +56% by public and private services), new solar and wind energy farms (+33%), and by agriculture and cattle farms (+1.7%). The net expansion of this sector in 624 has results from different trends. First, there are some crops in recession, especially open garden vegetables (-407 has), and rain-fed multi-crops areas that usually contain a mix of almond, vineyards, olive groves and natural vegetation (-115 has). Second, this recession is partially balanced by the expansion of almonds (+132 has) and greenhouses (+306 has). Third, agricultural areas considered as abandoned increased in 208 has, while at the same time newly plowed areas that were not planted yet increased in 435 has, especially in Nacimiento and Bajo Andarax areas. Finally, the surface occupied by cattle farms experienced a notable increase of 60% (+145 has).

Population grew in 17% during the reported decade. The most remarkable observation is that statistics do not show a decrease in the overall hours devoted to paid work, as would be expected considering the economic recession and the sharp decline of the building sector (-61% of paid work hours). This decay has been balanced by an outstanding boost of employment generated by the services sector, especially in Almeria city and the largest towns. In addition, the public services and the industry, mining and energy production sectors did also increased their working hours. Interestingly, overall agricultural working hours decreased in 15% despite the expansion of work-intensive greenhouse farms. Another significant change is the increment in hours devoted to education, as well as to unpaid working activities such as household work or volunteering, whereas the reported time in leisure hours notably decreased.

Table 4.7 - Evolution of societal funds during the management cycle

		Land use 2005 (has)	Land use 2011 (has)		Human activity 2001 (Mhr)	Human activity 2011 (Mhr)
s	SOCIETY	45001	46554	SOCIETY	1883	2205
s-1	Households	2259	2546	Households	1731	2028
s-2	Residential	2055	2247	Physiological overhead	901	1068
				Unpaid work	161	365
	Education	28	29	Education	47	103
	Leisure & other	176	270	Leisure & other	622	492
s-1	Paid work	42742	44008	Paid work	151	177
s-2	Industry, mining & energy	1238	1648	Industry, mining & energy	12	15
	Water regulation & infrastructures	207	224	Building	22	8
	Public services	4314	4465	Public services	35	44
	Private services	167	255	Private services	66	95
	Agriculture	37001	37615	Agriculture	16	14
s-3	Almonds	7956	8088			
	Citric	1672	1647			
	Open vegetables	8697	8291			
	Olive grooves	5126	5086			
	Greenhouses	2888	3194			
	Vineyards	760	737			
	Other	486	475			
	Rain-fed & natural vegetation	8668	8552			
	Abandoned	489	707			
	Newly plowed	16	452			
	Cattle	242	387			

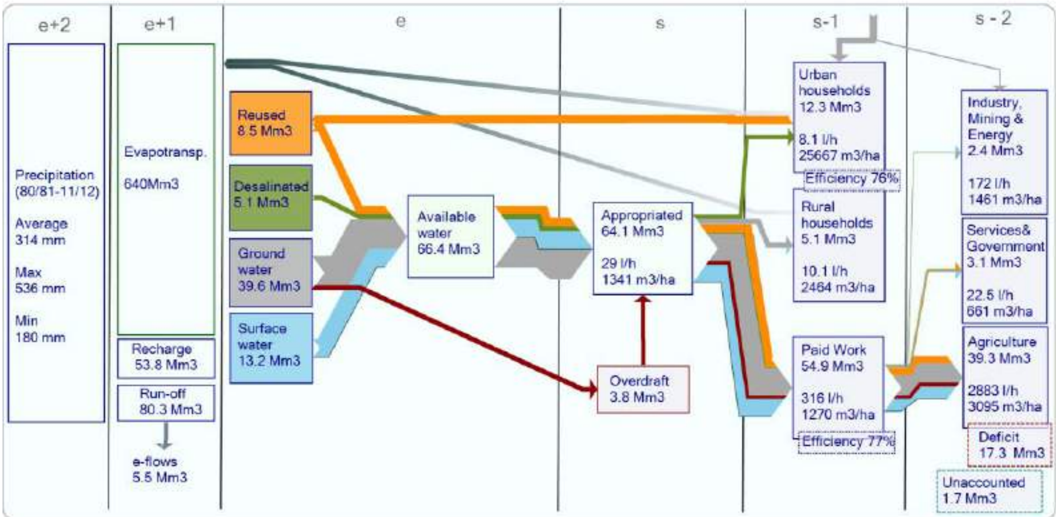


***Figure 4.1** - Water metabolism in the Andarax basin (2015)*

Regarding the water metabolism, Figure 4.1 presents an update of Figure 3.2 in Chapter 3 to the new accounting for 2015 in the RBMP 2016-20, as well as the intensive ratios of water use in relation to societal funds in 2011. Precipitation series were extended to 2011/12 and show a slight increase in statistical values. However, the recharge and run-off models were not updated and the new plan assumes the same hydrological regime. E-flows have not been implemented at all. The only remarkable change on the *e* side of the figure is the recognition of an official overdraft of 3.4 Mm^3/year for Bajo Andarax aquifer, with the ensuing reduction in groundwater availability. On the other hand, overdraft in Tabernas aquifer had been reduced from 0.6 to 0.42 Mm^3/year despite no reduction in withdrawals was reported.

Overall societal appropriation of water (*s*) slightly decreased in 0.3 Mm^3/year regarding 2005. Almeria city gross water use (*s-1*) also decreased in 0.5 Mm^3/year despite population and urban growth, thus becoming less intense per hour and hectare. The demand of other residential areas in the basin (rural households at *s-1*) grew in 0.6 Mm^3/year, becoming more intense per hectare of land use but yet maintaining more hours of human activity per liter of water. Gross water use of paid work activities decreased mainly due to the removal of golf irrigation as a demand accounted within the services sector of the Andarax basin. On the other hand, the new solar and cogeneration energy production plants raised industrial demand in 0.4 Mm^3/year. Both of these sectors are now generating more jobs per liter of water, especially the services sector which water accounting does not mirror the boost in jobs generation, neither the expansion of related land used. Technical efficiency of urban supply was not reported to increase. On the other hand, overall irrigation efficiency incremented in 4% as a result of modernization programs in Nacimiento and Bajo Andarax areas. According to the accounting, these efforts generated 2.2 Mm^3 of spare water resources that were assigned to attend additional demands from agriculture, increasing the net water use of the sector but maintaining its withdrawals constant. Notwithstanding, the reported deficit was only reduced in 1.2 Mm^3 because new demands appeared during the period. Despite the expansion of greenhouse farms shown in Table 4.7, no change in irrigated land was recognized in the RBMP 2016-20. Considering the average greenhouse water consumption, this would sum up to 1.7 Mm^3 that are out of balance and out of planning.

4.3. Discussion: a semiotic cycle of the WFD in the Andarax

The ALTAGUAX project was an initial loop of *narrating experience* ($d\vartheta$) (Figure 1.8 in Chapter 1), complementing the formal participatory process of the RBMP with a thorough identification of problems and proposals for actions in the Andarax river basin. The analysis of narratives during this process reveals the existence of several different perspectives about water management in the area, that sometimes conflict with each other while others ally. Stakeholders in the basin agreed in the core problems – unsustainability of water demand, aquifers overdraft and wastewater pollution – whereas they greatly diverge in the detailed causation of those problems as well as in the strategies to duly address them. In addition to the problems identified in the RBMP, stakeholders pinpointed structural issues corresponding to a social-ecological perception of rural communities' livelihood, critical claims towards institutional and political performance of the water administration, and eco-integrative perspectives on the economic development model.

Dominant narratives pervading the RBMP 09-15 combined a problem structuring from a deep ecology narrative mirroring the environmental objectives of the WFD, with a course of action that prioritizes new demands through supply-oriented measures, and ecosystem restoration as means to pursue those goals. The IWRM narrative based on water demand control has not significantly permeated dominant discourses and management actions but through efficiency as an intentional boundary discursive strategy, enabling strong coalitions among otherwise contested narratives. In addition, there is a clear defense of the role of technicians as water experts, and of a technical de-politicized management. This vision is deeply rooted in the hydraulic paradigm but perpetuated through IWRM story-lines (del Moral et al. 2014). On the other hand, those proposals questioning the efficacy and effectiveness of the water administration, or its capacity to cope with structural problems of sustainability are disregarded as too burdensome or beyond the scope of water management.

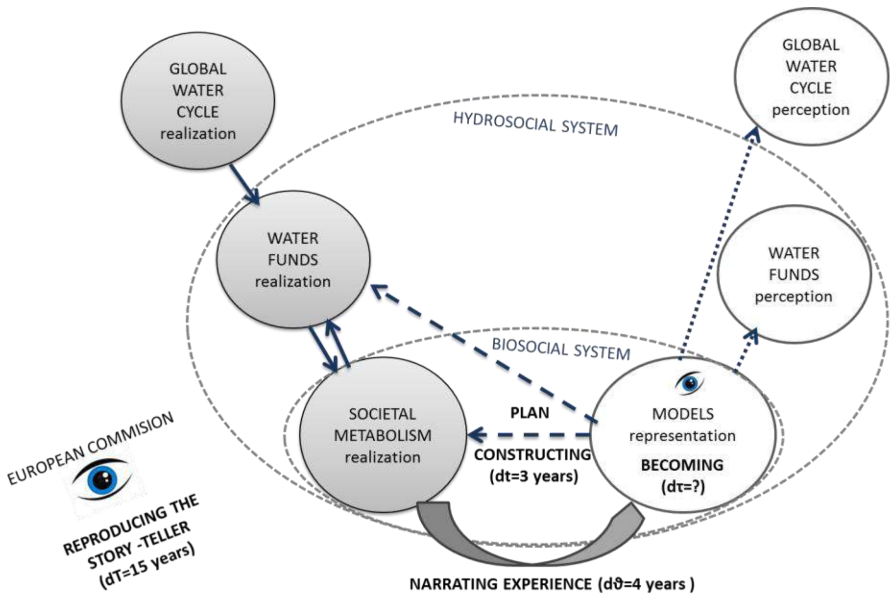


Figure 4.2 *- Semiotic process during the first cycle of the WFD in the Andarax basin*

The first horizon of the WFD (*reproducing the story-teller* dT=15 years) was reached with inchoate progress towards policy goals. A delayed endorsement and a halved *constructing* period (dt=3 years) liaised to the high budgeting requirements of the chosen management strategies in a context of financial austerity, stymied the implementation of the PoM. Not only the system did not noticeably change in order to pursue policy goals (*becoming*), but it is deferring EO for later planning horizons. The core strategy of irrigation modernization did not appear very effective in reducing the so-called 'deficit' despite accruing most of the available budget, neither in yielding a better status of water bodies. Furthremore, remarkable changes in the water metabolism were more due to an improvement of the information about water bodies than to social-ecological transformations prompted by the actions of the RBMP. The societal organization has not dramatically changed in the last decade because economic stagnation hinders large interventions, whereas the previous weight of the building sector has shifted towards private urban services. In the meantime, relevant trends of agricultural land abandonment in upstream areas or the continuous unplanned expansion of greenhouses remain unattended. The consequences of these trends are not reflected in the new plan draft at all. Moreover, there is no formal evaluation by the RBD on the implemented actions. This is the 'territorial un-government' described by Sampedro and del Moral (2014): the lack of comprehensive planning at the regional level on an ex-ante basis allowing uncontrolled growth of human activities, which later impacts are faced through techno-social fixes that create temporal buffers but do not actually solve problems.

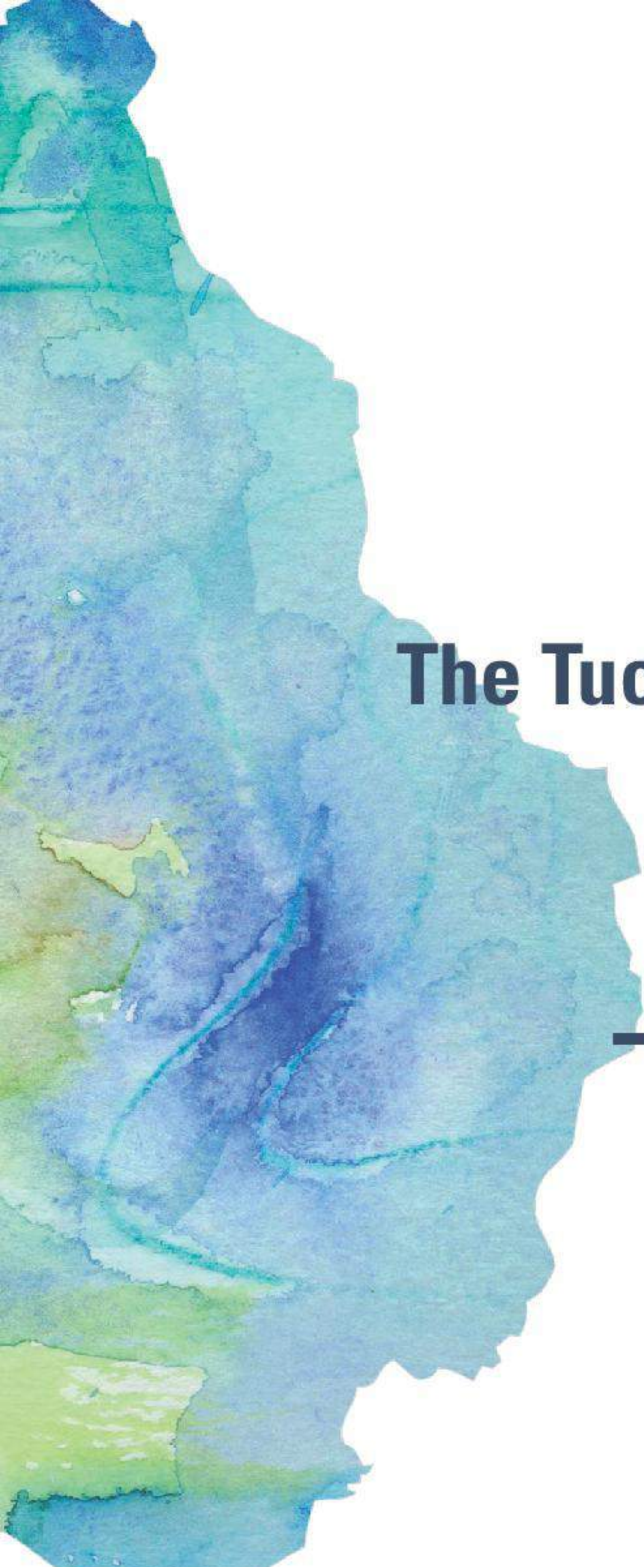
The second *narrating* experience (dθ=4 years) showed very little progress towards problem closure and a generalized mistrust to the water administration. Local stakeholders did not feel reflected in the current deployment of EO within the WFD, neither on the RBMP as a tool to cope with perceived water problems. On one hand, the ecological status goal in a river basin like the Andarax with centuries of social-ecological evolution is perceived unrealistic; on the other hand, the RBMP did not attend critical demands neither is driving significant social-ecological changes. In addition, there is a patent problem of insufficient information and transparency, and ineffective communication that has been set aside during the management cycle.

4.4. Conclusions

This chapter adds on the concept of semiotic process of water management in order to assess the first cycle of implementation of the WFD in the Andarax river basin. Despite the existence of contested narratives, the dominant discourse is still anchored within the hydraulic paradigm with some nuances from IWRM. Social accommodation of antagonistic perceptions is undertaken through purportedly win-win technological interventions, which so far have proved highly cost-ineffective or stagnated due to the costs-recovery principle of the directive. Other alternative claims are gainsaid but uncover a complex multi-level and multi-dimensional network of water problems that the RBMP does not echo. Perceptions about the lack of both discursive closure -inadequate problem definition through top-down environmental objectives- and problem closure –institutional incapacity to deal with complex problem-solving- unveil a serious problem of mistrust to the water administration that reinforces stagnation.

The management system during the first cycle of WFD was not reflexive, since it only mirrored those narratives that are in accordance with dominant ones, neither responsive, since the new RBMP does not build on the feedback from stakeholders. In addition, its adaptation capacity was meager, since the system barely changed to solve perceived water problems. Rather, the system was highly vulnerable to perturbations such as the financial crisis, regional political changes or the rejection of local stakeholders to implement cooperative actions.

PART III



The Tucson basin

Ese río creado en tu memoria,
con el solo lugar de tu recuerdo,
que se deshace cuando no lo miras,
que existe en tu vacío o en tu sueño

FRUELA FERNÁNDEZ

Introduction to case study: the Groundwater Management Act in the Tucson basin

In the setting of the SWAN Project (Sustainable Water ActioN): Building Research Links between EU and US (FP7-INCOLAB-2011), an interdisciplinary group of young researchers from Europe and America set a collaborative research agenda in order to promote a transatlantic dialogue on water governance. This goal was pursued through cooperation on comparative analysis of water management issues in different case study locations in the European Union and the United States of America. During meetings in spring 2013, the group agreed to focus on the Tucson region, Arizona, as the geographical area to realize a common case study in which to integrate our different models and approaches (Figure I2.1).

This part of the dissertation is my contribution to this collaborative research and it aims at reviewing the state of the art of current debates around the sustainability objectives in Arizona water policy focusing on the Tucson basin area. This is undertaken through a dialogue between water researchers and managers from Arizona and Spain, areas with a common background of hydraulic paradigm tradition in water management (Reisner 1993, Sauri and del Moral 2001)[33]. In the sake of a transdisciplinary research experience, this work has followed an iterative process in order to identify key management issues, research questions and sustainability indicators. It commenced with a first literature review and interviews to regional water managers in February-April 2013 that enabled drafting a set of scientific questions that were presented, reframed and prioritized in a participatory workshop in October 2013. The minutes of this workshop are presented in Appendix 4 including: 1) Identification of key management challenges; 2) research concerns and knowledge gaps; 3) stakeholder mapping. Some key research issues identified that I attempt to tackle in this research to different degrees are:

- The effect of changes in the socioeconomic structure over water demand
- The effectiveness of Tucson basin water Management Plans (MP) towards achieving safe yield by 2025

[33] Part of this case study will be published as a chapter in a book that will be the main research output of the students group. The chapter was coauthored by Nuria Hernandez-Mora (University of Sevilla), Aleix Serrat-Capdevila (University of Arizona), Leandro del Moral (University of Sevilla) and Ed Curley (Pima County).

- The impact of the groundwater credit system on the present and future dynamics of the water budget in the Tucson Basin
- The impact of groundwater dynamics on biodiversity conservation

Further collaboration with stakeholders is explained in the methodological section of the following Chapter 5. This introduction presents the institutional framework for water management in Arizona, a discussion of the concept of safe yield, an overview of the study area, and a review of stakeholders' perspectives around regional water management.

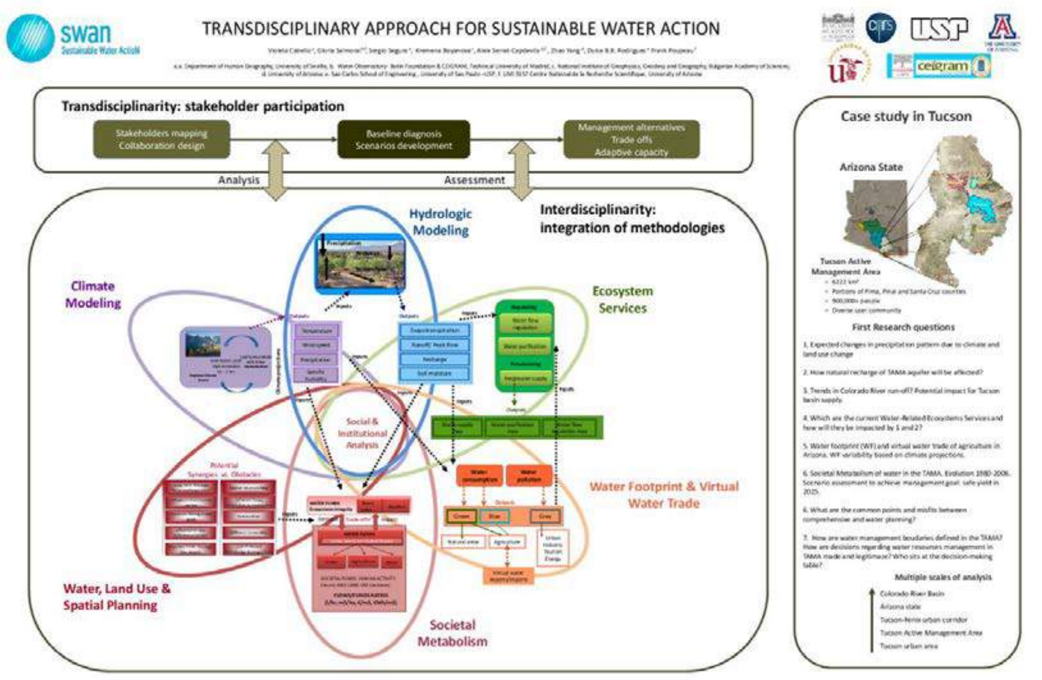


Figure I2. 1 - Poster presented to the VIII Iberian Conference on Water Planning (Lisbon, December 2013): theoretical approach to an interdisciplinary framework in SWAN to be applied in the Tucson basin

Institutional framework for water management in Arizona

The evolution of water law and management in Arizona has been characterized by an ongoing effort to augment water supplies to support unconstrained economic and population growth (Waterstone 1992, Akhter et al. 2010). The institutional context for water management cosists of a complex system of regulations, norms, agencies and public and private operators that have evolved over time in response to changing socioeconomic, political and technological realities.

Groundwater use in Arizona was largely unregulated until the approval in 1980 of the Groundwater Management Act (GMA) while surface water law is governed by the prior appropriation doctrine. Before 1980, groundwater abstractions were only limited by the reasonable use doctrine (Jacobs 2009). Starting in the 1940s, strong socioeconomic and population growth resulted in significant aquifer overdraft and land subsidence. By the 1970s it was clear that something had to be done to regulate groundwater pumping. In 1976 the Arizona legislature created a groundwater commission to write a groundwater law, but political resistance from agricultural users (who held a majority of groundwater rights) prevented any proposal from advancing. Negotiations finally succeeded when the Federal Government conditioned the approval of funding for the construction of the Central Arizona Project (CAPR) to the passing of groundwater management rules in Arizona (Akhter et al. 2010). The GMA was approved.

The GMA designated four Active Management Areas (AMAs) in parts of the state where groundwater pumping was particularly intense around major urban and agricultural areas (see Figure I1.2). A groundwater management goal was established in each AMA to be achieved by 2025 through the implementation of 5 consecutive management plans. The management goal for the Phoenix, Tucson and Prescott AMAs is to achieve safe yield. The goal for the Pinal AMA is to maintain the agricultural-based economy for as long as possible. In 1995 a portion of the Tucson AMA was separated out and became the Santa Cruz AMA. Its management goal is to maintain safe yield and prevent local water tables from experiencing long term declines.

Figure I2. 2 - *Arizona counties and Active Management Areas*

Within the AMAs, existing groundwater uses prior to 1980 received a 'grandfathered right' and a moratorium on new irrigated agricultural land was imposed (Megdal et al. 2014). Management plans for each AMA established mandatory conservation goals for groundwater users that apply to most non-exempt wells (wells that pump in excess of 35 gallons/minute or 70.000 m^3/year) in the agricultural, industrial and municipal sectors (Jacobs 2009). The GMA established clear guidelines for the first three MPs but was vague on the requirements for the 4th and 5th, given the uncertainties associated with such a long-time planning horizon. Finally, the GMA created the Arizona Department of Water Resources (ADWR), centralizing all quantity-related water management responsibilities.

The three first MPs (1985-1990, 1990-2000, 2000-2010) followed specific guidelines established in the GMA. As of August 2015 (when this paper was completed) the IV MP had not yet been and the III MP's rules continue to apply (SYTF 2015). MPs are primarily regulatory documents establishing conservation programs for the different sectors (municipal, agricultural and industrial). They are not true management plans in the sense of roadmaps towards achieving objectives (Megdal et al. 2008 p. 35). Management per se is done by providers in a decentralized governance regime, without regional (basin scale) common planning over resources allocation.

The CAPR is the primary source of renewable water supplies in central Arizona. Every year it delivers 1.6 MAF (1900 Mm^3) of Colorado River water to portions of the Phoenix, Pinal and Tucson AMAs (Prescott and Santa Cruz AMAs do not have access to CAPR water), representing 57% of Arizona´s 2.8 MAF entitlement of Colorado River water. The Central Arizona Water Conservation District (CAWCD) was created to manage and operate the CAPR and generate the resources to repay the federal government for the investment. To help ensure long-term water supply given that Arizona's CAPR water entitlement exceeded instate demand, a groundwater recharge and storage system was devised to utilize Arizona's surplus water and firm its supply from Colorado River water.

Given the expectation that the municipal water sector would continue to grow, the Assured Water Supply (AWS) program was created to link water and land use planning (Jacobs 2009). The draft rules set by the ADWR in 1988, that restricted allowable groundwater declines, encountered strong opposition from the development community, agricultural sector and cities without CAPR access (CAGRD 2014 p. 17). The outcome was the AWS program, a new rules package (approved in 1995) that requires all new urban developments to provide proof of physical, legal, and continuous access to a 100-year supply of water.

The Central Arizona Groundwater Replenishment District (CAGRD) was created in 1993 to facilitate municipal water users meeting the AWS rules. It encompasses the Phoenix, Tucson and Pinal AMAs. Membership in CAGRD allows landowners and water providers without access to CAPR water or other renewable supply to use mined groundwater to prove AWS. Members pay the CAGRD to replenish any water pumped in excess of AWS rules. The CAGRD thus serves a double function of firming larger amounts of CAPR water while at the same time facilitating development and growth in the AMA regions by ensuring 100 years of water supply to those municipal users outside CAPR service areas. The CAGRD has priority over the recharge capacity of CAWCD sites (CAGRD 2014 p. 11).

A final but important piece of the institutional puzzle for water management at the state level is the Arizona Water Banking Authority (AWBA), created in 1996 with the double purpose of allowing intrastate and interstate water banking and of facilitating the firming of Arizona's full Colorado water entitlement. Funding for the operation of the AWBA comes from property a tax on all real-state owners in the 3 CAPR counties (Maricopa, Pinal and Pima), and a fee on groundwater pumping and state appropriations (Megdal et al. 2014). Until 2012 AWBA had spent 197 M$ and stored 3947 Mm^3 in long-term storage credits, the majority in Phoenix and Pinal AMAs (AWBA 2012). AWBA does not hold rights and it does not operate a water market. It also does not own or operate storage facilities and is not responsible for recovering the water it stores—the CAPR recovers the water in times of shortage (Jacobs 2009). The target of the AWBA is to store up to 3.6 MAF (4493 Mm^3) to ensure long-term municipal uses in times of shortage (AWBA 2012).

The ADWR regulation functions are mainly related to conservation programs, data collection, water accounting and information generation and technical support to regional water management processes within the AMAs (ADWR 2015a). The GMA established Groundwater Users Advisory Councils (GUAC) in each of the AMAs to act as intermediaries between the multiple parties involved in the water management networks and the ADWR and AWBA. The Tucson AMA is an acknowledged example of active regional cooperation. Besides the GUAC, several initiatives have been undertaken in the last 15 years analyzing and promoting regional water policies. The Institutional and Policy Advisory Group (IPAG) was specifically formed to develop the recharge plan for the TAMA in 1995[34]. Recently, a new working group called the Safe Yield Task Force (SYTF) was created to coordinate efforts towards the achievement of the AMA's management goal.

[34] http://www.azwater.gov/azdwr/WaterManagement/AMAs/TucsonAMA/TAMA_GUAC.htm

The Tucson basin

The Tucson basin is the name given to two wide alluvial valleys, bounded by mountain ranges, in which the city of Tucson (Pima County) is located. The climate is semiarid, with erratic precipitation patterns concentrated in two periods during winter and summer and has an annual average rainfall of 12 inches (310 mm) (NWS-NOAA 2015). The basin overlies the interconnected aquifers of the Avra Valley and the Santa Cruz River (Figure I2.2a), and this delimitation was used by for water planning by the ADWR to establish the Tucson basin as a management unit in the GMA. The Santa Cruz River used to flow in Southeastern-Northwestern direction, as did the groundwater flow of the underlying aquifer, until aquifer overdraft in the region caused water table depletion and drying up of the river in the second half of the twentieth century. Most of the runoff and aquifer recharge originates from higher precipitation rates along the mountain front during both winter rainfall and monsoon summer storms. Ephemeral channel recharge from storms in the basin can also be significant.

After Phoenix, the TAMA is the second most populated region in Arizona, with a total population of one million people distributed in four main urban areas (City of Tucson, and towns of Marana, Oro Valley and Sahuarita), other urban sprawl areas (thirty Census Designated Places) and part of the Tohono O'odham Nation. Human occupation in the basin dates back to paleo-indians of the Archaic Period (~7000 BC to 300 AD), who already planted corn on the banks of the Santa Cruz River. The Hohokam culture flourished from 200 AD in-after, developing irrigation farming with a whole range of new crops varieties that propelled population growth and a more settled lifestyle. Spanish settlers arrived in 1695, introducing cattle and extending irrigation through acequias, what increased the pressure over the river. The Anglos commenced to settle after the United States bought the area to Mexico through the Gadsden Purchase in 1854. New agricultural projects triggered conflicts between upstream and downstream users in the Santa Cruz. The new Anglo developers won the dispute marking the decline of the traditional irrigation system. During next decades, 33 new ditches in addition to the three main canals were built by corporations and entrepreneurs. As the competition for river flows intensified, ditches were dug deeper to be able to divert the diminishing water shares. In 1887, a large flood eroded the riverbed down to the water table level, disconnecting all the diversion canals from the river. Thereinafter, wells were opened to maintain agriculture, although it was not until the beginning of the twentieth century that electricity enabled massive groundwater withdrawals. The Santa Cruz River used to flow in Southeastern-Northwestern direction (Figure I2.2 a), as also did the groundwater flow of the underlying aquifer, until aquifer overdraft in the region caused water table depletion and drying up of the river in the second half of the twentieth century.

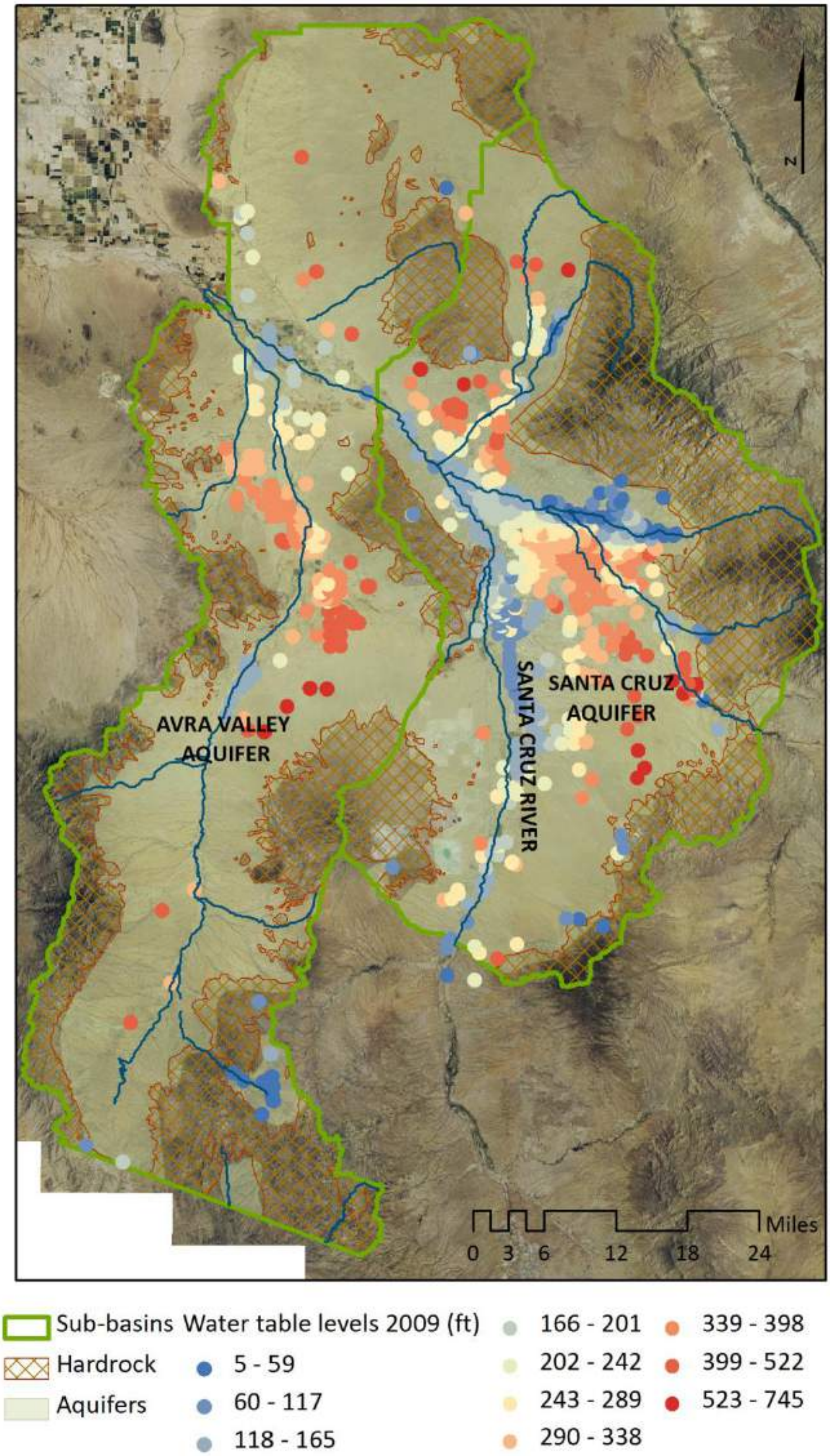


Figure I2. 3 - Tucson basin location and hydrological features

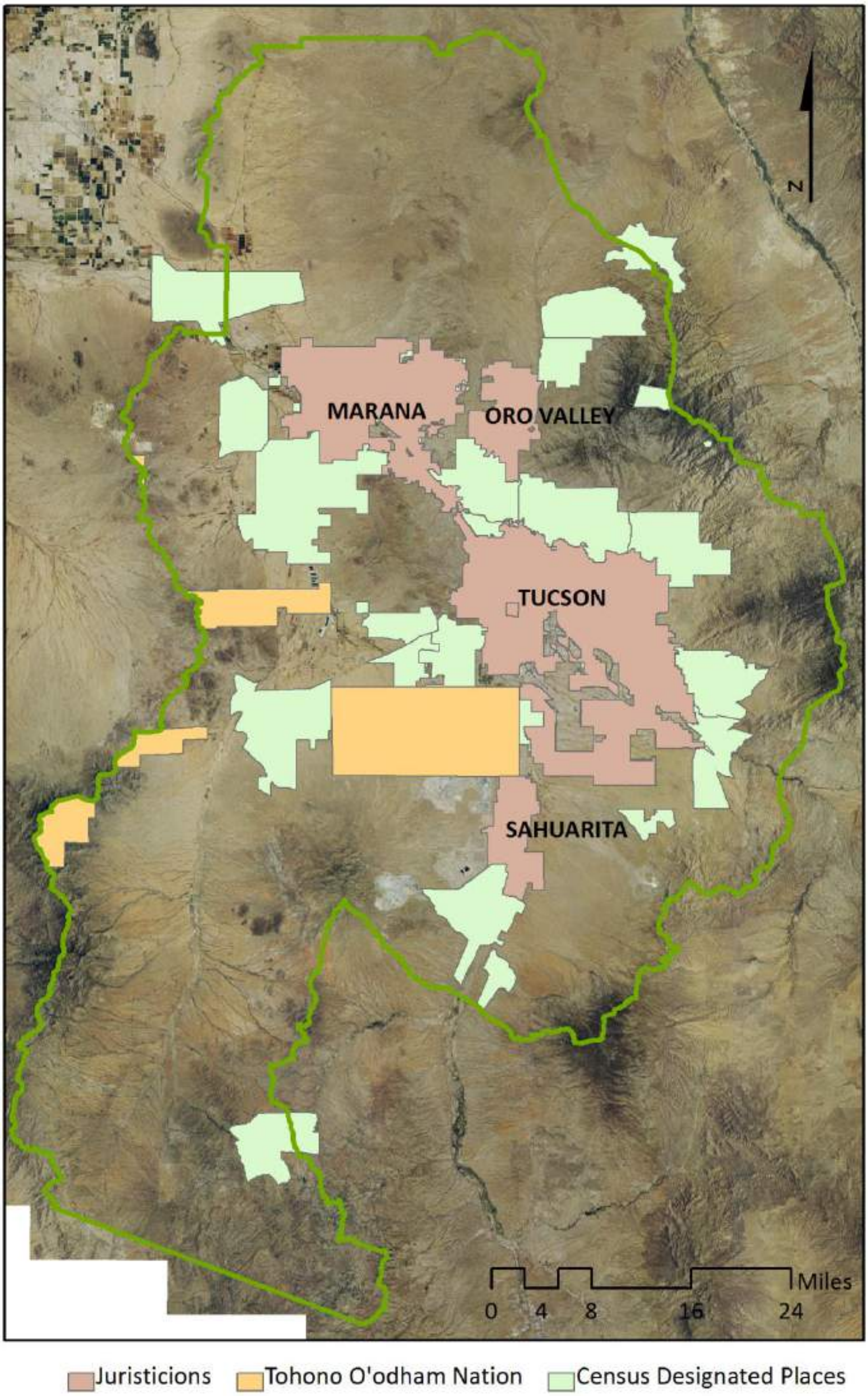


Figure I2. 4 - *Urban areas in the Tucson basin*

Safe Yield and Sustainable Yield

Safe yield is technically defined as a groundwater pumping level in which human pumping is equal or less than recharge. This concept as a management goal arose during last century from over-abstraction and aquifer mining in many regions in the United States. While safe yield is a laudable goal in severely over-exploited aquifers with pumping regimes that by far exceed natural recharge, it may not be the optimal sustainability goal to aim for in the long term, especially in regions with riparian areas and other groundwater-dependent systems. The explanation is very simple if we look at a simple mass balance of an aquifer:

Change in Aquifer Storage = Recharge – Pumping + GW Inflow – GW Outflow – Riparian ET

If, as in the case of safe yield, *Recharge = Pumping*, then the mass balance is as follows:

Change in Aquifer Storage = + GW Inflow – GW Outflow – Riparian ET

GW is groundwater and ET evapotranspiration. As it can be seen, the two negative terms in the equation are responsible for the decrease in aquifer storage. When all of the recharge is pumped, the groundwater outflow and the riparian evapotranspiration may not replenished by the groundwater inflow. Thus, with a progressive lowering of the water table, systems depending on shallow groundwater will likely be impacted by this negative mass balance. In Arizona, safe yield is calculated for whole AMAs as black boxes where flows come in and out of groundwater stocks. This enables to blur spatial distributional aspects, like the economic impacts of increasing cones of depression, the dry out of riparian vegetation and natural springs, or the deterioration of groundwater quality affecting other uses. This 'groundwater budget myth' has for long been unraveled by hydrologists, but still persists in the management realm (Bredehoeft 1997, Sophocleous 1997, Devlin and Sophocleous 2005).

In response to these critics, the concept moved to that of sustainable yield referring to a pumping rate that accounts for such impacts in a long-term perspective to groundwater resources management (Maimone 2004, Zhou 2009). A sustainable yield would be achieved by assessing what level of pumping and what spatial distribution will have the least undesirable effects over groundwater dependent systems (Zhou 2009). This requires a negotiation of compromised sustainable pumping rates that can be maintained in different loci of the same aquifer while entailing the lowest trade-offs over others. In words of Molle (2011) 'because of the fluid nature of water, my use, right, vision or values are not independent from those of other people equally connected to the same hydrologic regime'. Therefore, participatory mechanisms become as instrumental for the success of that negotiation as sound scientific evaluation of trade-offs, which will be always subjected to power asymmetries and variations of political clout.

Perspectives about water management challenges

In light of the transition from the third to the fourth MP, several dialogue processes with stakeholders were held in the TAMA with the aim of contributing to the development of the plan. The processes were led by the Water Resources Research Center (Medgal et al. 2008, Megdal and Lien 2008), the PIMA Association of Government and The City of Tucson (WISPS 2010) and the Regional Water Assessment Task Force (Kiser et al. 2011). The most ambitious work was the Water and Wastewater Infrastructure, Supply and Planning Study (WISPS) that gathered 124 stakeholders from different typologies in a two years process of dialogue that finally anchored a five years action plan for 2011-2015. The outcome reports from these efforts gather the different perspectives existing within the TAMA water community, their points of consensus and divergence. From hundreds of comments received, Kiser et al. 2011 (p. 8) tailored the following grand goal as a point of departure for a collaborative regional water planning: "it is essential to ensure the region has a safe, reliable and sufficient water supply to meet the current and future needs of people, the environment and the economy". Within this umbrella, water management needs are pinpointed using a similar inclusive discourse (Box 1) in a vast effort of synthesis of multiple perspectives into areas of concurrence.

- There needs to be more collaboration and cooperation in managing water resources at a regional scale.
- Current water resources should be fully utilized, including CAP water, effluent and rainwater/storm water.
- New water supplies need to be acquired/developed.
- Conservation initiatives and education should be implemented at a regional scale. The era of cheap water is over. Rates will need to be increased to build new infrastructure, meet water quality standards, acquire new supplies, and improve allocation of water resources.
- Regional water policy should be consistent with the natural limits of the region and should consider evolving climate conditions

***Box I1.1** - Water management needs from the Regional Water Assessment Task Force meetings (source: Kiser et al. 2010)*

There is a repetitive accord along the reports from those workshops on the need for establishing a framework for regional collaborative water planning, opened to participation of multiple stakeholders. However, the views on how to arrange this process greatly vary from those conceiving participation as 'having a seat' at the decision table (assuming a limited number of seats) to those advocating for open inclusive processes to deal with "conflicts between the environment and growth; between existing residents and new residents; between core city residents and suburban residents; between urban and rural residents" (Barry 2011 p. 34).

Another common concern is the claim for achieving sustainability, albeit as it is usually the case, perceptions over what sustainability means diverge. While environmental stakeholders clearly link sustainability with a distributed achievement of safe yield that takes into account environmental needs, there are other stakeholders that perceive sustainability as the increment of water supply to meet increasing demands. Overall, there is a clear polarization on the key sustainability issue in Arizona: urban growth. Barry (2011) shows how the contrasting perspectives about growth drive most of the statements on how water should be managed, and lie at the bottom of the complexity of how to organize regional water planning. He classifies these perspectives over the continuum: growth as a desirable outcome, as simply inevitable (but we need to be prepared and carefully plan for it), or as a harmful outcome. In his view, these perceptions over growth are related to the defense of contrasting water management paradigms. The prevailing paradigm defended by growth as a good outcome or as simply inevitable is the traditional supply-oriented approach based on a "sound management and technological expertise". This is the narrative from water utilities which are in a more advantageous position to influence decisions than the rest. The challenger paradigm opposes to this view defending the priority of environmental needs as a constraint to growth, the uncertainties over the future of water supply and the focus on demand management and soft local infrastructures instead of very costly technologies. The term 'paradigm' is used by the author as a synonym of shared vision/perception. Remarkably, the IWRM paradigm is used in the discourse of the business community as means to defend allocative efficiency as priority criterion for water management decisions (water allocated to the most profitable ends). Not in opposition but more aligned with the acknowledgement of uncertainties and the need to face them, the adaptive management paradigm was defended by some regional water managers. While repeatedly claimed as important sectors, agricultural interests[35], Indian nations and mining interests were not active in the processes.

[35] The agricultural sector was interviewed by Megdal 2008a and Fleck 2013; relevant arguments from these works are summarized in Table I2.1.

Table I2. 1- Perspectives about water management from different stakeholders

Type of stakeholder	Domain	Values about water management goals	Perception of growth
Regional water managers	Water system	Ensure enough supply for increasing demands; multilevel cooperation	Harmful outcome/ Simply inevitable
Municipal water and wastewater utilities	Water system	Ensure enough supply for increasing demands; regional cooperation	Simply inevitable
Jurisdictions managers	Political	Augment water supply; governance of private entities; regional cooperation; sustainability	Simply inevitable
Environmental stakeholders	Ecological	Environmental water needs; living within limits; soft-infrastructures & conservation; safe yield	Harmful outcome
Business stakeholders	Economic	Ensure long-term supplies for economic growth in the region; paradigm of economic rationality; IWRM; transparency and open participation	Good outcome
Elected officials	Political	Collaboration among multiple stakeholders, consensus; augment supply; infrastructures	Simply inevitable
Neighborhoods	Social	Open and inclusive participation; elites control politics; uncertainty; precautionary principle; water quality	Harmful outcome
Individual stakeholders	Environmental/ Social	Living within limits; soft-infrastructures; conservation; water quality; water-energy nexus	Harmful outcome
Agricultural interests	Economic	Flexible management to allow adaptation to economic markets; compensation for land conversion	Simply inevitable / Harmful outcome
Indian nations	Cultural/ Economic	?	NA
Mining interests	Economic	?	NA

5
CHAPTER

Water use and sustainability in the Tucson basin: Implications of a spatially neutral groundwater management

Arizona has developed strong regulatory mechanisms to ensure long-term sustainable water use and to integrate land and water use planning for the most populated areas (Jacobs 2009). The sustainability objective in Arizona's water policy is based on the concept of safe yield, that is, that the extraction of groundwater on a basin-wide and long-term basis is no more than is naturally and artificially recharged. As discussed in the introduction to the case study, this concept has been criticized by hydrologists because it can be interpreted as implying that by achieving a balance between recharge and pumping results there will be no detrimental impact on the aquifers and their dependent systems (Zhou 2009, Molle 2011). As sustainability objective the concept of safe yield may be considered as rather reductionist because it refers exclusively to the flows in and out of an aquifer, without taking into account other hydrogeological, socioeconomic and ecological criteria. Nevertheless, it is a challenging management goal that requires implementation strategies with ensuing evaluation systems.

Until the arrival of Colorado River water through the CAP in 1992, the city of Tucson and surrounding municipalities depended solely on groundwater for their water supply. As in other rapidly growing areas of Arizona, intensive groundwater pumping resulted in significant decreases in groundwater level and in consequent subsidence of areas of land. The approval of the 1980 GMA, and the resulting transformation of the institutional context for water management in Arizona, introduced changes in the way groundwater was managed and used in the Tucson basin. These included restrictions in water use patterns for municipal, industrial and agricultural users through binding conservation programs. The arrival of CAP water brought a new water source to the region that helped to substitute for diminishing groundwater resources. The recharge and recovery program was created to manage the new "renewable resources"[36] that came with the CAP, thereby allowing the region to optimize water allocation by storing large volumes of Colorado River water in overexploited aquifers. The Tucson basin is now recognized as a reference for its conservation practices to curb demand and its innovative groundwater management system (Jacobs and Holway 2004, Megdal et al. 2014).

[36] The Arizona water community uses the term "renewable resources" to refer to the inflow of Colorado River water through the CAP. However, the consideration of Colorado water as renewable is questionable given the serious impacts that this interbasin transfer, coupled with all the other ones that the Colorado suffers, causes in the donor river basin, the severe drought-related variability of water availability, the uncertainty surrounding climate change predictions and the amount of energy required to pump Colorado water all the way to the Tucson basin.

However, these practices are not exempt from critical assessment, since the techno-social fixes they present avoid facing the core challenge of uncontrolled urban growth head-on (Hirt et al. 2008, Akhter et al. 2010). There are two elements of Tucson's water management system that have not yet been evaluated: a) the impact of water conservation programs on overall demand and b) the spatial dynamics of the groundwater management system.

The objective of this chapter is to delve into the debates about sustainability of water management in the TAMA, with the aim of providing insights on the limitations and challenges of the current management strategies to achieve the safe yield goal. Specifically, I look at three relevant questions formulated in collaboration with local stakeholders: How has the water metabolism evolved since the approval of the GMA and the arrival of the CAP to the Tucson Basin? Is water demand decreasing as an effect of conservation programs? How does the spatially neutral approach to groundwater management shape vulnerabilities in the socio-hydrological system?

The chapter is organized in three sections. After this introduction I present the methods in section 5.1, in which I adapt the WMSES framework to the case study, depicting the region as a coupled water-human system. The quantitative analysis of water metabolism is complemented with a thorough review of academic literature and water planning reports, interviews with local experts and participant observation of water planning meetings. Research was conducted in two phases, between February and July of 2013, and between November 2014 and March 2015. Section 5.2 contains the results structured in i) a historical perspective on water use and planning; ii) a description of the evolution of societal metabolism of water after CAP arrival; iii) a discussion of the interplay between conservation programs and water demand; and iv) a spatial analysis of groundwater management. A discussion of the effectiveness of current water management strategies to cope with long-term and spatially equitable[37] sustainability is further presented in section 5.3 followed by the conclusions.

[37] Equity implies a social or political consensus about the 'fairness' or 'justice' of the distribution of costs and benefits of a policy or program. Yet achieving a consensus concerning the fairness of a particular distribution is almost impossible. Thus, equity is a complex and value-laden concept (Truelove, 1992). However, the notion of 'spatial equity' enjoys a long tradition in spatial planning practice. In a physical sense, spatial equity can be understood as the equitable development of land use. In a socio-economic sense it can refer to the equitable flow of goods and services from one spatial arena to another. In both senses, spatial equity is a parameter for sustainable development and can be defined as both a process and an outcome. As process, it involves the redistribution of the overall resources and development opportunities and/or the optimization of locally existing resources and development opportunities of an area. As an outcome, it envisions a region or area where such redistribution or optimization is achieved and sustained (Buhangin 2013, Kunzmann 1998).

5.1. Methods

The Tucson Basin as a complex holarchic Social-Ecological System

The water management system in the Tucson basin is extraordinarily complex; there is likely no way to depict it in simple terms. Multiple layers of institutional reforms, governance networks, technological fixes and contested interests are entangled, framed by the particular political culture of the USA. Figure 5.1 shows the multi-axes representation of relevant analytical levels in the Tucson basin. On the eco-hydrological axis, the basin is part of the huge Colorado River Basin, whose water is the main source for the region. Relevant groundwater dependent ecosystems are riparian areas rooted in shallow water tables along mountain range canyons. On the societal axis, there are three noteworthy markets influencing regional socio-economic functioning: agricultural commodities, housing and copper, which is main mineral extracted in the area (*s+1*). Socio-economic sectors using water to maintain their functioning are classified in urban, agriculture, industrial and Indian Nations at *s-1,* and subsectors at *s-2* (Figure 5.2). The governance levels were thoroughly presented in the institutional framework in the case study introduction.

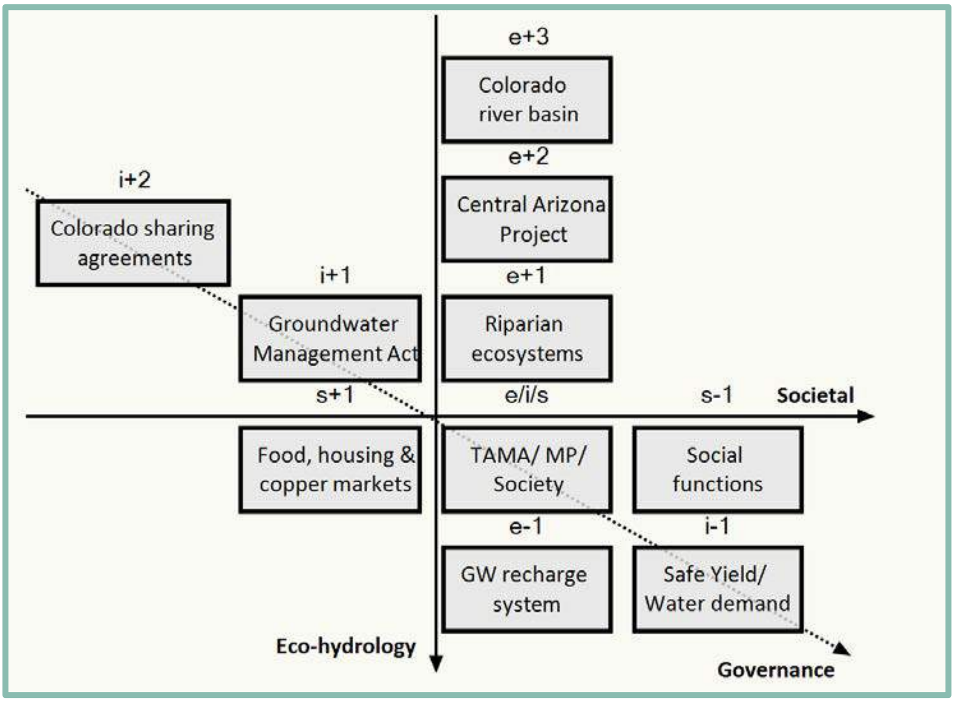


***Figure 5.1** - Multi-axes representation of holarchies in the Tucson basin. GW = Groundwater; MP= Management plan*

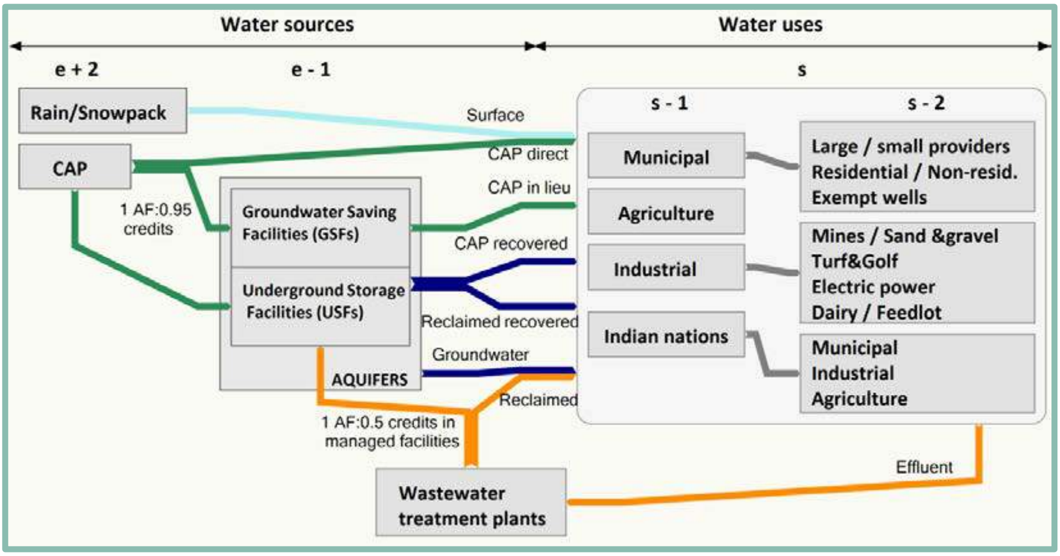


***Figure 5.2** - Water metabolism in the Tucson basin*

Figure 5.2 shows a dendrogram depicting the water metabolism system. Arrows are not quantified; they qualify the different water flows. CAP water can be used directly, instead of groundwater (CAP in-lieu) or recharged and then pumped again (CAP recovered). Reclaimed water is also directly reused or recharged and recovered. Each acre-foot recharged generates groundwater credits that can be recovered in the future, through two types of mechanisms:

- Underground Storage Facilities (USFs) are areas where CAP or reclaimed water is physically recharged, either through *constructed* injection wells or recharge basins, or other *managed* recharge mechanisms, by a diversity of private and public operators. This water can then be recovered (pumped) in the form known as CAP/reclaim-recovered water.

- Groundwater Saving Facilities (GSFs), also called in-lieu or indirect recharge, are locations where CAP water or effluent is used by irrigation districts instead of their irrigation groundwater rights. The surface water provider gets a groundwater credit for the amount of water that would have otherwise been pumped.

The recharge and recovery program distinguishes between water stored for recovery in the same calendar year (recovered water or short-term credits) or in a later year (long-term storage credits). In the latter case, 5% of each acre-foot of CAP water recharged or not extracted is considered the "cut to the aquifer", devoted to overdraft recovery. In the case of reclaimed water the cut to the aquifer is 50% if it is recharged in a managed facility, whereas reclaimed recharge from constructed facilities has no cuts.

Grammar

The methodology for quantitative analysis was deployed in four steps. I first analyzed the evolution of water flows in the TAMA water budget, using a 25 year long data series for the period from 1985 to 2009-10, disaggregated per source and sector for the whole basin. The series were plotted combining water sources per sector in an interactive visualization type Icicle tree[38] in the Quadrigram software (www.quadrigram.com). Table 5.1 describes the semantic categories of the variables used and Table 5.2 lists the data sources. Water flows typologies are established according to the TAMA water budget sources and end-uses, maintaining the same nomenclature.

Next, to address structural changes after recharged CAP water started to be recovered, I analyzed the evolution of societal metabolism of water between 2000/01 and 2010/11. The analysis includes societal funds, land use and human activity, and water flows per end use sector. Land use and cover categories were aggregated from those of the 2001 and 2011 National Land Cover Databases. Human activity has been calculated from demographic, economic and employment data from the American Census for 2000 and 2010. It should be noted that the methodology followed in both censuses differs, in that the former is an extensive one year inventory of the entire population while the latter provides the average variables of surveys to population samples during different years. Data for 2010 are averages of 5 years. Water uses per sector were averaged for the previous decade (1990-99 and 2000-09) in order to compare tendencies.

[38] https://philogb.github.io/jit/static/v20/Jit/Examples/Icicle/example2.html

Table 5.1- *Water grammar for the Tucson basin*

Role	Extensive variables	Unit	Description
FLOW	Available water sources	AF/ Mm^3	
	CAP direct		Water from CAP that is directly used without previous recharge
	Groundwater in-lieu		Water from CAP that is used instead of pumping groundwater
	CAP recovered		Water pumped from aquifers in exchange of previously recharged CAP water
	Reclaimed		Wastewater effluent directly reused after treatment
	Reclaimed recovered		Water pumped from aquifers in exchange of previously recharged wastewater effluent
	Groundwater		Water pumped from aquifer
STOCK	Overdraft		Difference between total water pumped from aquifers and natural + artificial recharge. Calculated in the water budget on a basin wide basis
FLOW	Water uses		Sum of total gross water use per each of the sectors
	Municipal		Water supplied by municipal providers for residential and non-residential use. It is composed by large provider's residential, large non-residential (Other urban services), lost and unaccounted, small providers, exempt wells and deliveries to individual. Exempt wells are estimated as 1 AF of annual demand per every four wells
	Mining		Water withdraw by mines
	Other economic sectors		Water used by economic sectors outside the municipal supply network: dairy and feedlot; sand and gravel extraction; electric power generation; golf and turf facilities; other
	Agriculture		Water used by agricultural sector
	Indian nations		Water used by Tohono D'Oham nation and Pascua Yaqui tribes
FUND	Human activity	Hours	Population in a given year per 365 days per 24 hours
	Households		Hours of non-paid activities, calculated as the difference between paid work hours and total human activity. The required data to disaggregate this sector are the Time Use Surveys which are only available in the United States at the national level but not at the state level.
	Paid Work		Hours employed in paid work activities. Calculated as the sum of employment in each sector per average

Role	Extensive variables	Unit	Description
FUND	Land uses and covers	Miles/ acres/ hectares	
	Forest		Sum of deciduous and evergreen forest surface categories of the National Land Cover Databased (NLCD)
	Shrubs		Shrub category of the NLCD
	Water bodies		Sum of water bodies, woody wetlands and herbaceous wetlands of the NLCD
	Barren land		Barren land category of the NLCD – mines area
	Cattle grassland		Sum of grassland and pastures categories of the NLCD
	Mining		Digitalized over orthophoto 2014
	Urban		Sum of high, medium and low density and open space categories of the NLCD
	Crops		Crop category of the NLCD
	Intensive variables	Unit	Description
FUND/ FUND	Employment	%	Hours in each economic sector out of total working hours in a year
	Dependency ratio	%	Hours of unpaid activities (households) out of total hours in a year
	Land occupation ratio	%	Land employed in productive human activities out of total land minus hard rock (not available land)
	Housing units density	Housing number/ mile^2	Number of houses per land unit
FLOW/ FUND	Income per capita	$/capita	Gross income per capita in a year
	Gallons per capita day	Gallons/cap*day	Municipal daily water demand divided by total population served
	Water use density	Acre-feet/acre	Water use per acre of land used
	Water use intensity	Gallon/ hour	Water use per hour of total human activity

Table 5.2 *– Data sources*

Data Type	Sources	Links (Accessed February 2015)
Rainfall	National Weather Service Forecast Office	http://www.wrh.noaa.gov/twc/climate/reports.php
Shallow groundwater areas	Pima Association of Goverments	http://gismaps.pagnet.org/subbasins/#/MapUser
Water table levels	Pima Association of Goverments	http://gismaps.pagnet.org/subbasins/#/MapUser
Wells inventory	Arizona Water Resources Department	https://gisweb.azwater.gov/waterresourcedata/WellRegistry.aspx
Artificial recharge	Arizona Water Resources Department	http://gisdata.azwater.opendata.arcgis.com/
	Arizona Water Banking Authority	http://www.azwaterbank.gov/Ledger/defaultIntrastate.aspx
Long-Term Storage credits	Arizona Water Resources Department	http://www.azwater.gov/azdwr/WaterManagement/Recharge/default.htm
	Central Arizona Project	http://www.cap-az.com/index.php/departments/recharge-program
Water accounting areas	Pima Association of Goverments	http://gismaps.pagnet.org/subbasins/#/MapUser
Water budget	Arizona Water Resources Department	http://www.azwater.gov/AzDWR/Watermanagement/AMAs/TucsonAMA/TAMAOverview.htm#waterbudget
Demography, housing, income& employment	American Census FactFinder	http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t#
Land covers	Multi-Resolution Land Characteristics Consortium	http://www.mrlc.gov/
Crops and prices	National Agricultural Statistics Service	http://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS

In the third stage, I analyzed the evolution of water conservation targets for the municipal and agricultural sectors. The different components of municipal demand were included in the water budget alongside the population served by these subcomponents (large municipal residential and none residential, small municipal and exempt wells). Gallons per capita per day were calculated by simple division of those variables. Agricultural demand wais contrasted with precipitation and crop prices seriesdata. Precipitation time series for the weather station in the city of Tucson were obtained from the National Weather Service Forecast Office. Data for evolution of crop patterns and prices were obtained from the National Agricultural Statistics Service (available starting in 1996).

Finally, I conducted a spatial assessment of groundwater management. Available GIS data for groundwater recharge and recovery sites was analysed, as well as location of groundwater users and the changes in aquifer levels between 2000 and 2010. The latter were interpolated via point measurements with Inverse Distance Weighting using ArcGIS 10.1. Long-term groundwater storage credit data for each recharge area is only available for the AWBA credits. The long-term storage credits held by other institutions (about 50% of all long term credits) were inferred by combining the ADWR total accounting per owner updated in February 2015 (ADWR 2015b), the annual status report of the TAMA recharge plan (ADWR 2007) and data from CAP recharge sites (CAP 2015). T Being based on a series of assumptions, the estimates cannot be considered to be fully accurate, but can be deemed sufficiently good for the purpose of establishing a spatial reference regarding where the water is being stored.

Collaborative research and participant observation. Literature, management and planning reports review

As explained in the introduction, in the sake of a transdisciplinary research experience, this research was conducted through collaborative interaction with stakeholders in Tucson. Pereira and Funtowicz (2006) define transdisciplinary "as a specific form of interdisciplinarity in which boundaries between and beyond disciplines are transcended and knowledge and perspectives from different scientific disciplines as well as non-scientific sources are integrated". In this view, the common idea about the existence of "complex problems in society that need a combined effort of researchers of different disciplines and stakeholders from society, policy and industry" (Merkx et al. 2007) is understood not just as a practical need, but as an epistemological challenge, that could be expressed through the contraposition between 'public participation' and 'going beyond the academy'.

The research process started with the definition and validation of research questions (Appendix 4), but continued through the establishment of a more permanent dialogue with the Sustainable Environment Program of the Pima Association of Governments[39] in terms of exchanging data and producing relevant information to their work and that of the Safe Yield Task Force. The outcome of this dialogue was a report on multi-criteria analysis of sustainability indicators for seven different sub-regions in the TAMA named Water Accounting Areas. The indicators were agreed with the stakeholders and gathered in a geodatabase for future sharing and reuse. The report is presented in Appendix 5 and has supported the interpretation of results and discussion in this chapter.

The main part of the research has been conducted during two research stays at the University of Arizona from March to July 2013 and from November 2014 to March 2015. During the second time, two regional water management meetings were attended as participant observant, the Safe Yield Task Force meeting January 23rd and the Groundwater Users Advisory Committee of February 28th, 2015. Discussions on how regional planning is moving forward to face identified management challenges were held in those meetings. Preliminary observations were discussed with local experts from the University of Arizona and the ADWR during two interviews conducted in January and February 2015.

In order to draw the institutional framework, the following water management and planning documents were reviewed:

- Arizona Department of Water Resources 1999, Third Tucson AMA Management Plan.
- Arizona Department of Water Resources 2010, Draft Demand and Supply Assessment. (Preliminary document of the 4th Management Plan).
- Tucson AMA Institutional and Policy Advisory Group 1998, Regional recharge plan.
- Medgal. S.B., Smith Z.A., Lien A. M. 2008. Evolution and Evaluation of the Active Management Area Management Plans. Report of the Water Resources Research Center.
- Arizona Water Banking Authority 2012, Annual plan of operation.
- Arizona Water Banking Authority 2014, Recovery of water stored by the AWBA. A Join plan of AWBA, ADWR and CAP.

[39] http://www.pagregion.com/tabid/76/default.aspx

5.2. Results

Evolution of water use

This section explores the evolution of the TAMA as a socio-hydrological system since the approval of the GMA, linking changes in the institutional context to those in water use. The information presented is extracted from a thorough review of water planning reports (ADWR 1999, 2008 and 2010a; AWBA 2012 and 2014; Megdal et al. 2008; and TAMA 1998) in combination with data from the last update of the TAMA water budget until 2010. The data are presented using the Icicle visualization[40] in Figure 5.3. It illustrates the evolution of the different sources of water used in the whole Tucson basin (big upper square) and per sector (four small lower squares) in 1990, 2000 and 2009 (different colors are used each water source). In addition, Figures 5.4 and 5.5 show the temporal evolution of the data.

1980-1990: Responding to challenges. While the CAP was being constructed, the first TAMA MP boosted water conservation programs by setting conservation goals for each sector. The target of 140 gallons per capita day (GPCD) was set for the municipal sector. The Base Conservation Program (BCP) was approved for the agricultural sector establishing groundwater allotments based on irrigation efficiency targets[41], water duties[42] and water duty acres for the reference period of 1975 to 1979. Specific programs were developed for each type of industrial use permit. Mandatory water use reporting requirements were set and water accounting started in 1985. As Figure 5.3 a illustrates, during this period all sectors relied almost exclusively on groundwater, with the exception of some reclaimed water used by the municipal and agricultural sectors. Indian nations represented a small share of total water demand (1%) while mining was already relevant (Figure 5.5). The municipal sector was already the biggest water consumer, steadily growing from 41 to 48% of total water demand during this period, while agriculture fell from 42 to 32% of overall water demand as a result of the gradual reduction in irrigated acres (see Figure 5.4).

---

[40] The interactive visualization will be available until August 2016 at https://violetacabello.quadrigram.com/space/#/vzy/TAMA4

[41] Efficiency defined as final water uptake per water delivered

42 Calculated for each farm unit as irrigation requirements divided by total acres planted from 1975 to 1979 and multiplied by irrigation efficiency target.

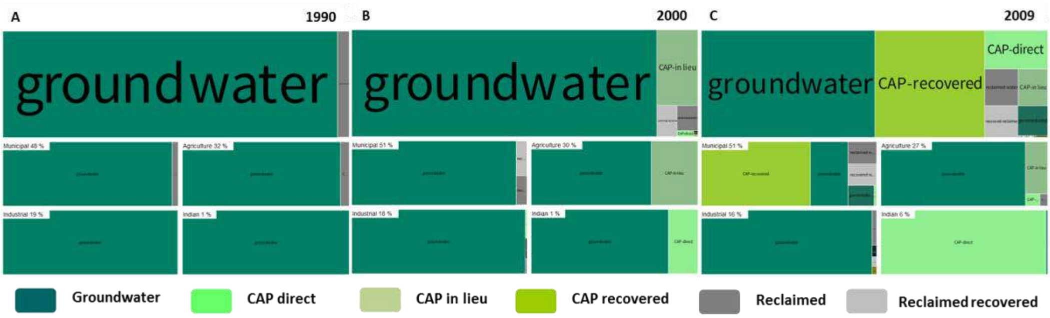


Figure 5.3 - Sources of water used for the TAMA (upper half of the figure) and per sector (lower half) in 1990 (A), 2000 (B) and 2009 (C)

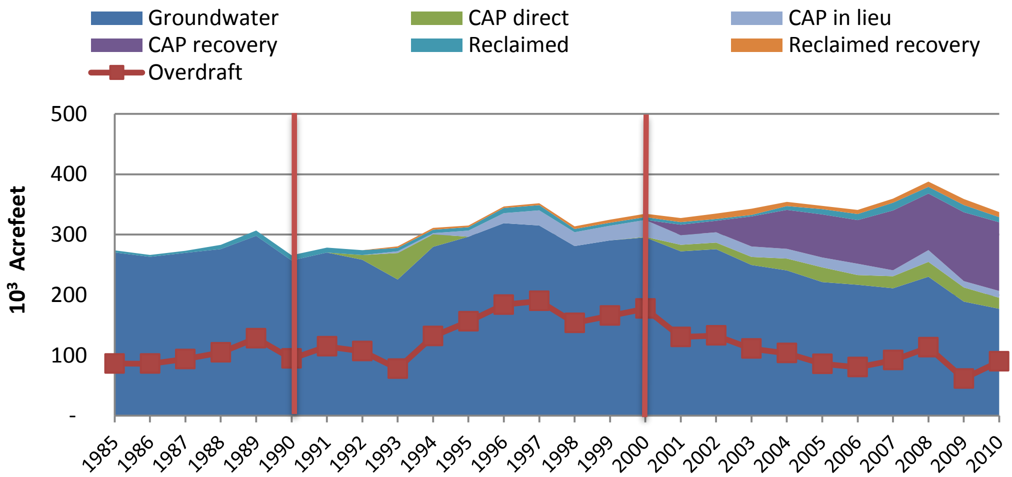


Figure 5.4 - Evolution of water use per source and groundwater overdraft

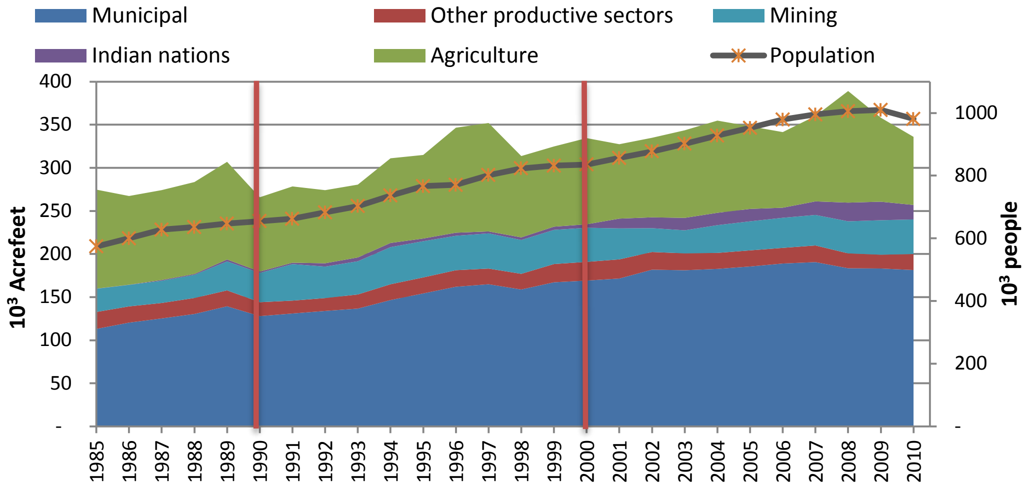


Figure 5.5 - Evolution of water use per sector

1990-2000: Adapting. CAP water arrived to Tucson in 1992 (Figure 5.4). One of the main objectives of the 2nd MP was overcoming legal, institutional and structural barriers for utilization of new supplies from CAP and reclaimed water (Megdal et al. 2008 pp. 90-91). Most of the laws, programs and institutions in place to firm CAP water (for instance AWBA or CAGRD) were created during this period. In the TAMA, the regional recharge plan was enacted as the new device for the achievement of the safe yield goal by storing excess CAP water underground (IPAG 1998). While the second MP renewed conservation programs it also introduced flexibility measures in both the agricultural sector—in order to facilitate adaptation to the evolution of market for agricultural products—, and in the municipal sector for small providers who had encountered difficulties achieving the 140 GPCD target. The highly controversial efficiency target for agriculture was set at 85% in this period. In addition, if farmers did not use their entire groundwater allotment in one year, they were allowed to "bank" this water which became “flexibility credits” for future recovery (Fleck 2013).

CAP water started being used for the city of Tucson municipal supply in 1993. It was treated to drinking standards and delivered through the water distribution system that had only conveyed groundwater in the past. Due to the different nature of CAP water (chemical composition, pH), it dissolved and re-mobilized mineral concretions that had accumulated inside the pipes over the years. This resulted in brown and unappealing water coming out of the taps. The consumer protests that ensued led to the abandonment of its direct municipal use after less than two years. Tucson had to revert to groundwater use while alternative solutions were developed to indirectly use CAP water for the city's water supply.

Groundwater use by the mining sector significantly increased in 1991 in 8449 AF (10 Mm^3), remaining constant the rest of the decade. According to the TAMA water budget, the groundwater in-lieu program started in 1992, redirecting direct CAP use to agricultural production (albeit not in a significant share until 1998), in exchange for the accumulation of long-term storage credits. Municipal providers subsidized the cost of part of this CAP water to farmers accruing the generated LTCS in exchange for municipal groundwater pumping for residential water supply. The result of all these parallel processes was groundwater annual overdraft dropping down in 1993 but increasing again a year later and peaking at 189,916 AF (154 Mm^3) in 1997 (Figure 5.4).

2000-2010: complexifying. The 3rd MP inaugurates the decade of groundwater storage and recovery. Between 2001 and 2010 there were 7 different sources of water used in the Tucson AMA: groundwater, direct use of CAP, CAP in-lieu, CAP recovered, reclaimed, reclaimed recovered as well as small quantities of surface water or low quality groundwater. While all water sectors diversified their sources of water, the greatest change throughout this period was observed in the municipal sector, which by 2009 was using 60% of recovered CAP water as well as water from five different other sources. The recharge infrastructures and the institutional framework created in the previous decade permitted increasing municipal demands to be met while simultaneously replacing direct groundwater use with CAP recovered water. Annual groundwater overdraft started to decrease significantly (Figure 5.4). Another noteworthy change was the reallocation of CAP water to the Indian nations and tribes following the Arizona Water Settlements Act of 2004. As observed in Figure 5.5, the agricultural sector is the one driving overall variability in demand and, in turn, instability of annual groundwater withdrawals. In addition, conservation programs were substantially softened during the 3rd MP, substituting conservation targets with the Best Management Practices program that tailors the set of improvements towards conservation to each end-user instead of setting a common goal.

Evolution of societal metabolism

With the aim of widening the discussion to other relevant dimensions of sustainability, this section compares two snapshots of the societal metabolism of water (for 2000 and 2010). Table 5.3 shows societal funds and moving average water flows for the two decades, alongside some metabolic indicators (intensive variables). Indian nations demand has been disaggregated and added to final subsectors (municipal, agriculture, other economic sectors).

During this period, the land occupation ratio increased by two points, driven mainly by the urbanization of shrubland areas with an average annual growth ratio of 3.3%. In addition, the housing density rose from 1 to 1.2 houses per square mile. A significant fact is that the small surface devoted to agriculture is surpassed by large-scale mines.

Conifers forested area decreased by 11.7%, mostly in the Northwest Catalina peaks. A positive environmental change was the increase in surface area of water bodies by 40%, especially wetlands, partially because of the groundwater recharge sites but also due to riparian restoration projects. In regards to human activity, the ratio of total working hours to total human activity increased despite increased unemployment in many urban areas, especially for those with lower incomes such as South Tucson, Summit, Three Points and Drexel Heights. This was compensated for by jobs generated in new urban areas, resulting in an overall employment rise of 13%. The economic model of Arizona has been based on the services sector coupled to urban growth (Jacobs 2009). Indeed, the services sector grew more in terms of employment generation, particularly in education, health, professional science, recreation and food services. This unveils the role of the University of Arizona as an important economic driver for the region. In addition, Arizona is famous as being a destination for winter seasonal retirees who help to boost the services economy. The demographic evolution shows two clear trends: a process of ageing and a permanent domination of the group aged between 18 and 25. On the other hand, the building and real estate sectors lost importance in regards to fraction of the total economy, although both grew in absolute terms. Agriculture and mining are smaller, but yet increasing sectors. The overall income per capita increased by 27%.

Most water uses are positively correlated with the evolution of the employment pattern. For instance the sand and gravel water use decreased with the declining weight of the building sector in the overall economy. Main water use increases were observed in residential and urban economic activities (non-residential municipal), in parallel to the growth of the services sector and the expansion of urban areas. Mining is the only activity that grew in employment without mirroring increments in water flows, thus becoming more efficient per hour of human activity. On the other hand, agriculture augmented its average consumption by 13% during this decade. Overall water efficiency improved per hour but decreased per acre (from 2032 m3/ha in 2000 to 3432 m3/ha in 2010) linked to the process of densification of urban areas.

***Table 5.3** - Societal metabolism evolution during the 3rd MP*

		Land use (miles^2)			Human activity (10^6 hr)			Water use (10^3 AFY)	
		2000	2010		2000	2010		2000	2009
e+1	Forest	162	145						
	Shrubs	3235	3216						
	Water bodies	7	10						
	Barren land	17	16						
s	Land occupation	451	486	Total human activity	6810	7990	Gross water use	306	346
s-1				Paid Work	501	657	Economic sectors	197	209
s-2	Crops	42	43	Agriculture	1.4	2.3	Irrigation	97	110
	Grassland	52	53				Dairy & feedlot	0.07	0.1
	Mining	NA	50	Mining	2.5	4.4	Mining	39	34
	Urban & developed	307	340	Building	38.7	40	Sand & gravel	4.1	3.9
				Manufacturing &Retail	140	163	Electric power	2.1	3.5
				Real State & financial	29	35	Golf & turf facilities	7.4	8.4
				Other urban services	254	362	Other urban services	39	43.5
				Government & military	35	50	Other	7.2	5.3
s-1				Households	6308	7333	Residential	109	136
s	Land occupation ratio (%)	0.19	0.21	Dependency ratio (%)	93%	91%	Water use density (AF/acre)	1.06	1.11
	Housing units per mile^2)	1.0	1.2	Income ($/cap)	19,959	25,454	Water use intensity (gl/hour)	14.67	14.11

From a sustainability perspective, it is important to point out that the TAMA water management system depends on two external resources: i) Imports of practically 100% of food requirements since agricultural production is mainly devoted to cotton and cattle-feeding products. ii) Low-cost energy from the Colorado dams, and the availability of the Navajo Generating Station used for pumping CAP water and is lifting it 2900 feet from the Colorado to South Tucson city. Regarding the latter, the CAP is the major single energy consumer in Arizona, with an annual consumption of 2.8 million megawatt-hours (CAP 2010). Ninety percent of this electricity is supplied by the Navajo Generating Station coal-fired power plant in Page, which also supplies energy to the Tucson Electric Power Company. According to Eden et al. (2011), the estimated energy intensity of CAP water when it reaches Tucson is 3,140 KWh/AF (2.54 KWh/m^3), which is four times bigger than the average for groundwater pumping.), which is four times larger than the average for groundwater pumping. Interestingly, the current (2014) rate for CAP water is only 140 $/AF (0.11 $/m3), thanks to good energy efficiency management and the revenues obtained from sales of surplus NGS energy (Eden et al. 2011). As shown in Table 5.3, water used for electric power generation within the Tucson basin is a small but increasing share of the overall budget. Increasing regulations over emissions and shortage predictions in the Colorado River basin are pinpointed as vulnerabilities of the system to an increase in energy prices (Cullom 2014).

Is water conservation curbing demand?

As described in the institutional framework, the use of water conservation programs was a core management device during the first three MPs, because such was specifically required by the GMA. Nevertheless, MP goals and requirements have evolved towards increasing flexibility and adaptability for each individual end-user, to the point that their effectiveness is currently being questioned (Megdal et al. 2008, Fleck 2013). The general accepted view is that demand is decreasing because of a reduction in the GPCD in the municipal sector. In what follows I examine available data from the TAMA water budget. The data are given for entire sectors, and are only disaggregated for municipal demand into the categories shown in Figure 5.6. Data for agricultural uses only indicates overall demand and irrigable acres, but does not identify actually irrigated land. The problem with this data format is that it does not allow distinguishing the effects of conservation programs on demand evolution from other drivers like climate, landing use or market changes (Megdal et al. 2008).

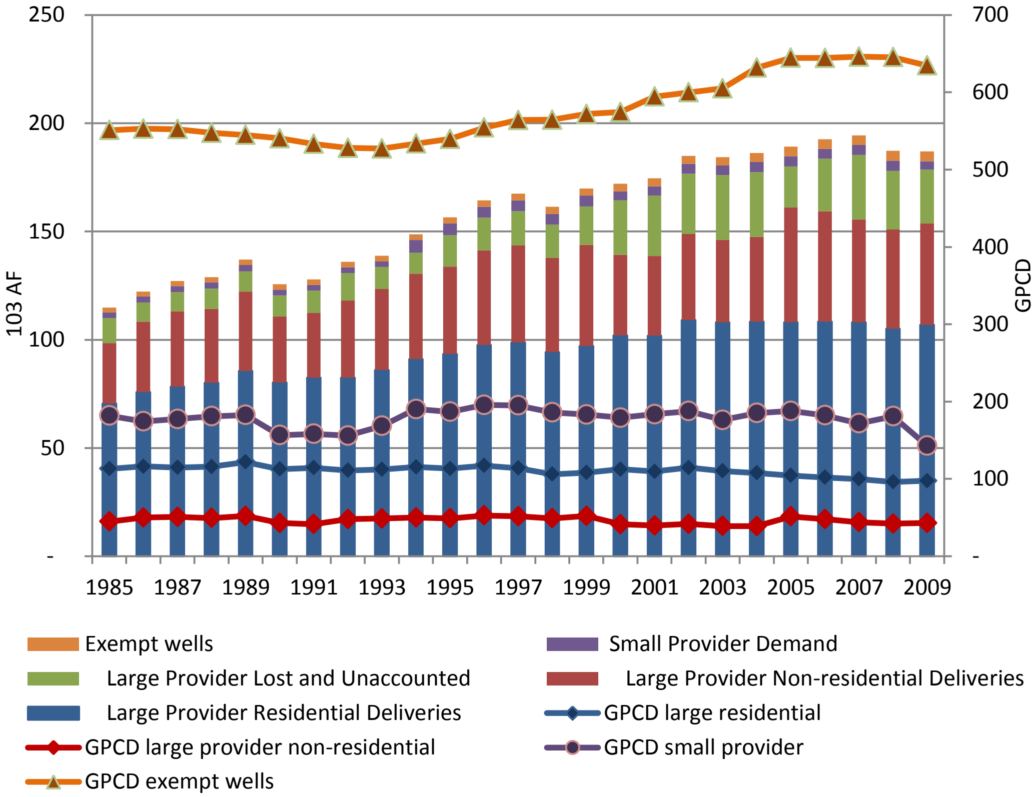


***Figure 5.6** - Evolution of municipal water use per user category and GPCD*

As observed in Figure 5.6, 58% percent of municipal demand is residential supplied by large water providers within what are called service areas. This demand grew continuously until 2002 when it stabilized. From 2007 to 2009, overall large provider residential demand decreased by 1223 AF (1 Mm^3) and the GPCD also decreased to 97 GPCD (370 lpcd) in 2009 (down from 122 GPCD in 1989). On the other hand, large-provider non-residential deliveries and lost and unaccounted increased in the last decade regarding the previous one. Small providers and exempt wells[43] are a very small share of the total municipal demand but have very high GPCD (181 and 645 GPCD per capita in 2009 respectively). Between 2000 and 2009, the population in the TAMA region increased in 173,864 people, but decreased in 2010 for the first time on record. The increase did not mirror increases in large-scale domestic demand. Updated data presented by the ADWR at the GUAC meeting of February 2015 confirmed the decreasing tendency in domestic demand, both in absolute and relative terms.

[43] Estimated as 1 AF of annual demand per every four wells.

The agricultural sector is a different and very complex reality. The GMA limited the possibility of increasing irrigable acres. Since 1995, these have remained relatively stable at around 36,200 acres (14,500 has, 1% of the total TAMA area), when 6210 acres of irrigation grandfathered rights were bought by Tucson water and transformed into non-irrigation rights (ADWR 2015a). There is no available data on actual irrigated acres per year per irrigation district, nor of the evolution of irrigation systems that could allow an assessment of the effects of conservation programs on agricultural demand. According to the ADWR (2015), average agricultural efficiency has increased from 50% to 80-90% as a result of the BMP program. Nonetheless, the literature is skeptic in regards to these results (Wilson and Needham 2006; Bautista et al. 2010). A very generous water allotment from the beginning and the introduction of flexibility accounts are pointed out as primary causes for ineffectiveness. According to these authors, conservation programs for the agricultural sector are so flexible that most farmers did not even change to the purportedly more flexible BMP program but, rather, remained in the initial Base Conservation Program.

Wilson and Needham (2006) and Fleck (2013) show rather than the conservation programs of the GMA, it is commodity prices (especially for cotton and alfalfa, which are water intensive crops) and rain that are the main explanatory factors driving agricultural water demand variability in central Arizona. Figures 5.7 and 5.8 show the evolution of agricultural water use, precipitation and the prices of the three main crops planted in the Tucson basin (cotton, hay and wheat). Agricultural demand is highly variable on a year-to-year basis, but fluctuates around a rather stable average. Until 1998, demand had a negative correlation with precipitation (Pearson -0.63) but since then, this relation is much less obvious. The 1996 Federal Agricultural and Improvement Reform Act decoupled crop prices and government subsidies from production, and increased planting flexibility (Frisvold 2007). Separating out the composite effect of this legislation from the evolution of crop prices and precipitation would require an econometric model that is outside the scope of this paper. Nevertheless, Figures 5.7 and 5.8 show that from 1996 onwards, the peaks in prices (especially for cotton) mirror peaks in water demand even when precipitation is not below the mean (Pearson 0.45 for cotton price, 0.3 for wheat, 0.44 for hay and -0.2 for precipitation). In 2008 peak water demand for the decade coincided with both lower precipitation and peak prices for all crops.

The analysis in the previous sections shows that: i) Overall water demand trend in the Tucson basin has continued to increase over the past 25 years although the pace of increase has slowed down by one third in the last decade (with respect to 1990-2000); ii) large municipal providers are making progress both in terms of cutting domestic demand as well as reducing groundwater overdraft; iii) for the other water use sectors analyzed, conservation has not been very effective as a demand reduction strategy; and

iv) agriculture, being highly affected by crop prices and precipitation, drives annual variability of overall Tucson basin demand and groundwater use. The capacity to continue curbing demand in the future by increasing conservation is considered small (Megdal 2015, ADWR 2015a). Instead, the ADWR plans to turn the core management strategy for the forthcoming 4th MP to supporting regional cooperation towards achieving safe yield during the next 10 years (ADWR 2015a).

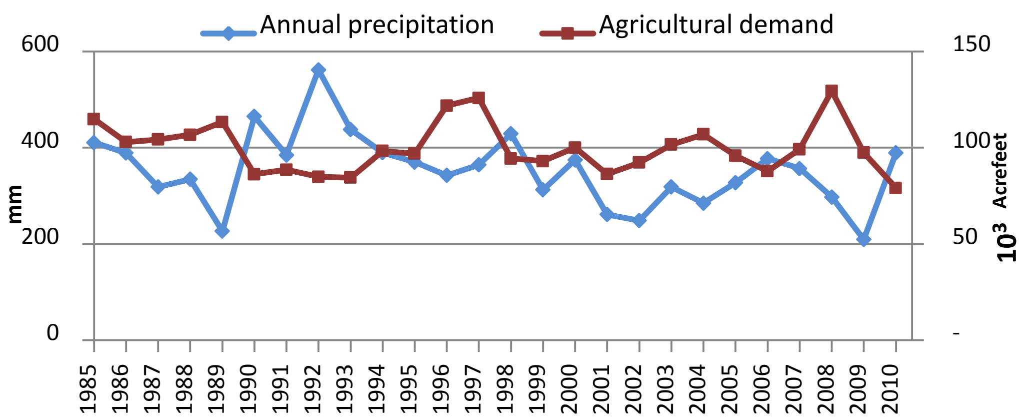


Figure 5.7 *- Evolution of agricultural water use and precipitation*

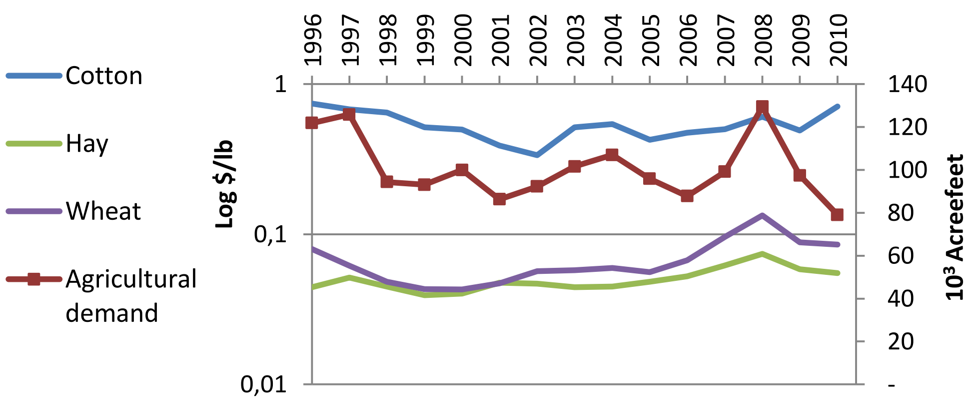


Figure 5.8 *- Evolution of agricultural water use and crop prices*

A spatial assessment of groundwater management

Undoubtedly, the main management strategy for achieving the TAMA goal of safe yield is the substitution of groundwater overdraft by other resources. Taken together, the total volume of CAP water and wastewater is three times the groundwater available through natural recharge. From 1993 to 2009, an average of 53% of total artificial recharge was recovered annually for municipal and industrial uses, 1.6% lost through evaporation in recharge sites, 7.4% remained as cut to the aquifer and the rest was stored as LTSC. The continuous increase of recharge capacity coupled with the renaming of most municipal groundwater withdrawals as recovered water, propelled a technical achievement of safe yield on a basin-wide scale (SYTF 2015). However, the spatial distribution of this achievement is not homogenous.

Table 5.4 - Water resources (AFY)

1908-2010	Funds	Precipitation (mm)	209 – 670
		Average	379
		Average natural recharge	81,964
2009	Flows	CAP inflow	197,289
		Reclamation	50,904
		Artificial recharge (CAP + reclaimed)	202,201
	Stocks	Annual recovery	124,118
		Long-Term Credits	798,844
		USF-CAP	630,545
		USF-Effluent	89,583
		GSF	78,716

As depicted in Figure 5.9 - A, there are 12 USF sites in the Tucson AMA — 7 recharging reclaimed water and 5 recharging CAP water — plus 6 GSF located in agricultural sites. Most of the recharge occurs in the Avra Valley and Pima mine road CAWCD sites using CAP water. Most of the recharge occurs in the Avra Valley and Pima mine road CAWCD sites, and uses CAP water. Most of the recharge of effluent takes place north of Tucson city. Groundwater recovery is mostly done by Tucson Water in the area of influence of the Avra Valley (CAP) and Sweetwater (effluent) recharge sites and delivered to the city (ADWR 2010 pp. 52). However, 90% of recovery and withdrawal wells are scattered throughout the municipal service area, with an important concentration in the large Mission and Sierrita Mine sites (located in southeastern Pima County), which

Arizona statutes require that groundwater recovery for municipal providers be located either within one mile of a USF site or in areas where groundwater decline is less than 4 ft/year (1.22 m/year). This limitation does not apply to those municipal users that join the CAGRD to meet the AWS requirements and can withdraw groundwater anywhere within their service or member lands (ML) areas. This was seen by municipal providers to be a major equity problem in the region (Megdal et al. 2008 pp. 24). Indeed, many of these providers have transferred their LTSCs to the CAGRD to enjoy the same advantages (ADWR 2010a pp. 55). As observed in Figure 5.9 - B, the CAGRD service area embraces all municipal providers while new member lands have three hotspots in northwest Catalina Mountains, eastern Vail and south Green Valley, all primary development areas within the TAMA. In 2009, 50% of groundwater (not recovered) pumping for municipal use was allocated to new developments, 37% as groundwater allowed under the AWS rules and 13% as excess groundwater that has to be replenished by the CAGRD.

The last piece of this complex puzzle is the LTSC system. The most recent update of credits accrued in 2014 showed a total of 1.4 M AF (1129 Mm^3, nearly four times total water demand in 2010), an increase of 80% since 2009 (Table 5.4). During the AWBA has been especially focused on recharge within the Tucson basin, accounting for 50% of the total LTSC. Other major owners are Tucson Water (15.6%), CAGRD (8.6%), Tohono O'odham Nation (6.2%), the Bureau of Reclamation (5%) and the Rosemont mine company Augusta Corporation (3%) (ADWR 2015b). In addition, there are 18 other entities owning less than 2% of the credits including small municipal providers (Marana, Oro Valley, Vail, Metrowater) and one irrigation district. As observed in Figure 5.9 C and D, the accumulation of credits is responsible for the recovery of aquifer levels in Avra valley and along Pima mine road. The rate of annual recovery of LTSC is around 1%. These credits can be recovered from anywhere within an AMA as long as consistency with management plan goals is maintained, and the recovery is inside or within three miles of the service area of a municipal provider or irrigation district. The credits owned by AWBA have the purpose of assisting municipal and industrial uses in case of shortage, meeting Indian water rights and fulfilling management goals; they have a specific recovery plan (AWBA 2014).

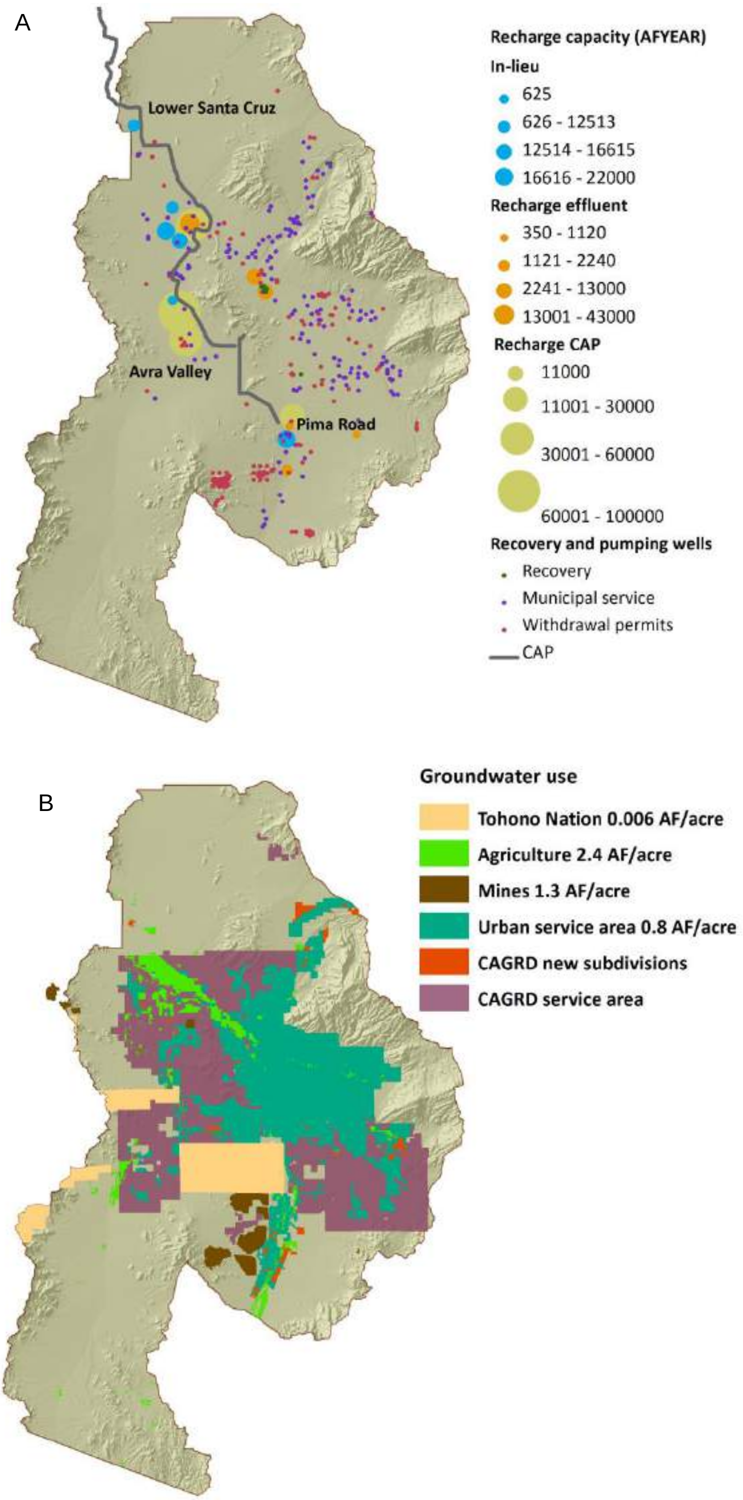


Figure 5.9 - *A- Recharge capacity and pumping wells; B- water users location*

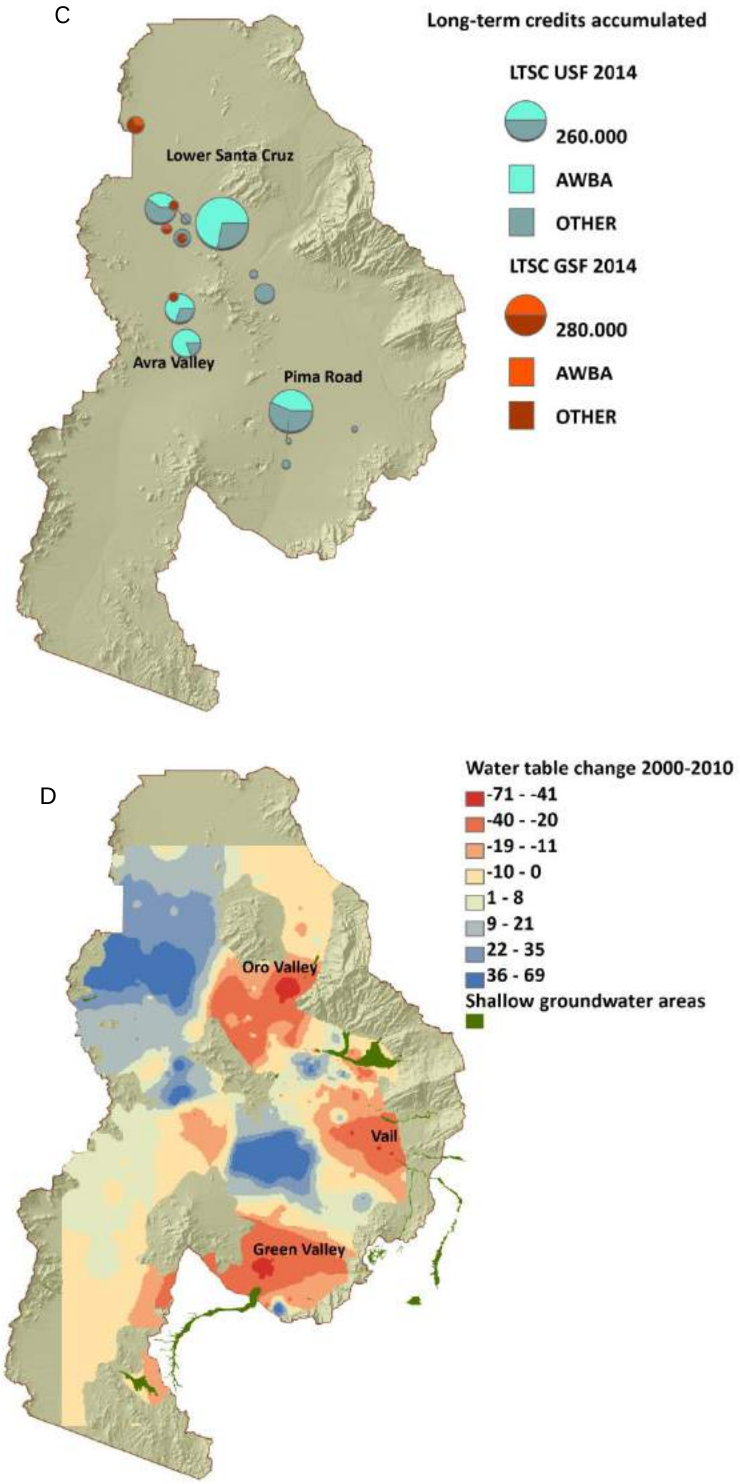


Figure 5.9 - C- accrued LTSC per site; D- groundwater levels change from 2000-2010 (feet) and shallow groundwater areas

There is no available spatial data online that provides an exact accounting of recovery and pumping. Nevertheless, water table levels are monitored and their evolution from 2000-2010 is displayed in Fig 5.9 D[44]. It can be seen that the areas where groundwater credits are being accrued are those undergoing water table rises of up to 60 feet (18 meters). Groundwater levels in the central part of the city of Tucson have also been rising, since the recovery in Avra Valley enabled Tucson Water to turn off its central well (that was driving the major cone of depression and land subsidence in the TAMA). On the other hand, few areas of water table decline remain. Peak declines of up to 71 feet (21.6 meters) are observed in north-east Oro Valley area were the major use sector is urban. The second relevant drawdown area is the southern Green Valley where some of the largest mines coincide with new developments and a large irrigated area, all of which rely mainly on groundwater. In addition, the eastern area of Vail has experienced similar average decreases of 44 feet (13 meters) in the last ten years. As can be seen in Figure 5.9 D, the mountain ranges around the Santa Cruz valley are home to the largest riparian ecosystems in what are known as shallow groundwater areas (SGWA, PAG 2012). These are sustained by natural recharge over high bedrock but many connect to areas of the aquifer with declining levels. Within the Tucson basin there are 20,537 acres of SGWA connected to wider systems (Figure 5.9 D), 46% of which overlap with areas of the aquifer having declining levels. It is noteworthy that there have been very few areas showing declines over 40 feet during the ten years monitored and in which recovery was forbidden.

In 2013, the ADWR launched a public consultation regarding a proposal named Enhanced Aquifer Management (ADWR 2013) that aimed to encourage groundwater recovery nearby recharge sites. It consisted on a calibration of percentage cuts to the aquifers depending on the distance to the recharge site: 0% within one mile buffer, 10% after the first mile but within the AMA, 20% outside of the AMA. All comments to the proposal were negative arguing that any disincentive to use CAP water would turn users towards groundwater again, resulting in increased water costs to customers or negatively affecting the emerging LTSC market (Tucson Water 2013, Brooks 2013). Alternative proposals included limiting pumping in areas with declining groundwater levels, limiting the allowable declining rate, or setting a tax based on observation of impacts in declining areas (Brooks 2013). The final outcome of the discussion was twofold: i) a requirement to improve information of the water budget, and ii) a proposal to project more pipes to allow CAP water to reach more areas within the TAMA. On one hand, the SYTF has recently proposed subdividing the Tucson basin into seven water accounting areas as a tool to improve water planning (ADWR 2015a). On the other hand, water providers are also working on cooperative Wheeling Programs with

[44] The figure shows interpolated data for monitored wells between September 2009 and March 2010. For a detailed visualization of wells location and levels visit the interactive map of Pima Association of Government http://gismaps.pagnet.org/subbasins/#/MapUser

the aim of building the infrastructures required to deliver CAP water to all urban service areas experiencing declining water tables[45].

5.3. Discussion: Growth, sustainability and spatially neutral groundwater management

This chapter has examined the evolution of water metabolism with particular focus on the changes induced by the arrival of CAP water to the TAMA, and with the aim of contributing to the debate regarding water management strategies to achievement sustainability objectives in the Tucson basin. The goal of safe yield imposed by the Groundwater Management Act has been pursued by a combination of i) reducing demand for existing uses through conservation practices (i.e. improving efficiency), ii) limiting the expansion of new demands and iii) bringing new resources to the region to substitute for the use of groundwater. Dissecting the effect of each of these strategies is a difficult task, since multiple interconnected layers of regulations have been overlaid during the past 30 years without a discrete assessment being carried out. Here, I have analyzed available data and pinpointed limitations in information.

The construction of the CAP was a tipping point in the water metabolism of the area, in the sense that it brought a drastic reconfiguration and diversification of water sources for the different sectors, while fueling the economy. This was enabled by increasing infrastructural and institutional complexity to make full use of what are deemed renewable resources from the Colorado River. Infrastructural complexity was deployed through a system of new facilities for recharge and storage, and by constructing new wells and pipelines to transport recovered water to the denser urbanized Tucson area. Institutional complexity was achieved through a series of new laws, programs, institutions and cooperative agreements that multiplied the decision-making nodes of a decentralized governance network.

Regarding the control of water demand, I have shown that, despite population growth, large municipal providers have managed to stabilize urban demand by reducing demand per capita. Therefore, if not reducing overall demand, at least the sector is now balancing savings against new demand. Other municipal components do not seem to be making significant progress and the apparent slight reductions in total municipal demand are mainly due to a change in accounting rules. Further, conservation programs for agriculture seem to not seem to be having the foreseen impact. On an annual basis, irrigation demand varies about a rather stable average, driving peaks in both the total Tucson basin demand and groundwater pumping on dry years and/or periods of high

45 http://www.azwater.gov/azdwr/WaterManagement/AMAs/documents/SAWUA_TW_EAMPresentation06042014.pdf

commodity prices. Since 2000, the Indian Nations have become significant players in the overall budget. Total water demand in the Tucson basin has grown continuously, although a slowdown in the pace of growth was observed from 2000 to 2010, in comparison with the previous decade. CAP water has partially replaced groundwater withdrawals, therefore contributing to overdraft reduction.

In regards growth limiting measures, the binding non-expansion rule for agriculture has been effective in controlling demand. Mines and other economic sectors have no limits imposed on their permits. The data indicate that mines have become more efficient in water use, but that their local impacts on water table levels are still very significant. Water uses are in general coupled to the trajectory of evolution of the economic sectors with a clear predominance of urban services. The Achilles heel of Arizona water problems is that of limiting growth in the urban sector, since the dominant economic model is tied to urban expansion (Akhter et al. 2010). All attempts to set constraints regarding groundwater overdraft that might affect development have been systematically thwarted. From 2000 to 2010 the development sector lost weight in the economy, but this is perceived as associated with the volatility of the housing market after 2008. According to the CAGRD Operation Plan 2014, the annual rate of membership drastically dropped since 2009, and so did their replenishment obligations. Most land lots have not been built upon and current projections show construction increasing over the next 10 years and peaking in 2021. Coupled with this, municipal water demand in the TAMA is projected to grow until 2045 (CAGRD 2014 pp. 49-51) by nearly 29.000 AF (35 Mm^3). It is however the lowest of the projections for the three CAGRD AMAs.

The lack of spatial disaggregation of the water budget makes it difficult to assess the extent to which improvements in efficiency in some urban areas are enabling growth in others. This 'spatial neutrality' in the accounting has a long tradition in USA since the Bureau of Reclamation started to pool the cost-benefits analysis of large infrastructure projects for whole river basins as means to justify their economic viability (Reinser 1993). What seems clear is that there is a disconnection between recharge and recovery in some areas, and that local impacts over the water table are still significant. The technical achievement of safe yield at a basin level is spatially uneven and there are wide areas in which overdraft continues, especially in new developments and large mines loci. Larger biodiversity hotspots are dependent on shallow groundwater and some of them partially overlap areas with declining aquifer levels from 2000 to 2010.

The new category of *recovered water* enables continued mining of groundwater without being properly accounted for in the overdraft equation. A proper accounting should reflect which part of the recovered water is actually CAP, which is reclaimed water (for instance the water that Tucson Water transports from Avra Valley to the city), and which is not (all the water recovered outside the area of impact of the recharge site), and should split the accounting of safe yield into different sub-regions according to that. The water accounting areas project is a good step in this direction. The regional network for water governance is aware of the impacts of the ill-defined spatial management strategy and is negotiating solutions. While it was initially proposed to constraint recovery near recharge, it seems instead that the final bet is for bringing recharge close to recovery through an expansion of the CAP infrastructure to reach more areas within the TAMA. Some have argued this is a straightforward solution to the current depletion problems (Tucson Water 2013), but at the same time this view may not properly account for the expected shortage of Colorado water acknowledged by CAP managers. Regional inequities are one of the main arguments leading to what has been termed 'river basins overbuilding' (Molle 2006). This term is used to name the vicious cycle between water scarcity and development of new resources, usually entailing critical impacts on ecosystems and increasing vulnerability of water users to variability in supply.

The AWBA recovery scenarios until 2024 show that municipal, industrial and Indian demands can be largely met with 66% of its actual storage (AWBA 2014 pp. 46). The main recovery mechanism that has been proposed is the exchange of short-term annual credits of municipal providers for LTSCs accumulated near recharge sites (AWBA 2014 pp. 55). Agriculture has low priority access to CAP water and thus it is the most vulnerable sector to potential Colorado water shortages. Nevertheless, it has grandfathered rights that could again increase the pressure in regards to use of groundwater. The AWBA recovery plan does not mention safe yield at all and so far there is no assessment of how recovery by other different owners would impact the management goal.

5.4. Conclusions

The problem of how to reconcile the positive and negative impacts of urban growth remains the eternally unresolved debate in the Tucson basin and in the American south-west. Questions regarding potential physical, socio-economic or environmental limits to growth are not even on the discussion table in Arizona. Water scarcity imposes a key limiting factor on the current urban growth-based economic model. However, an increasingly sophisticated governance regime has been devised to try to overcome this limitation.

Safe yield is a laudable management goal that has triggered important changes in the water metabolism of the TAMA. Management strategies of conservation, non-expansion of irrigation rights and new resources have been effective in progressing towards the achievement of safe yield, partially thanks to an intense cooperation among regional stakeholders. The municipal sector has been the most adaptive in reducing overdraft and stabilizing demand through conservation, yet it is responsible for the largest share of the overall demand which will likely keep on incrementing with new infrastructures. The agricultural sector will be key in future responses to drought since it drives inter-annual overdraft variability.

Yet, the discourse regarding CAP as a renewable resource, and the use of creative accounting devices veil an unequal distribution of impacts and vulnerabilities derived from the spatially neutral approach to groundwater management. Mines and new development areas count with privileged withdrawal permits that are causing important local impacts over water tables with potential effects over riparian ecosystems. How this spatial inequity is resolved appears the main sustainability debate of the next ten years when the GMA is to be assessed. Achievement of safe yield might be possible in most areas if new pipes are constructed to deliver CAP water to those locations, as long as no severe shortage in the Colorado River occurs. Whether this is a resilient or a ceteris paribus strategy that increases vulnerability will be seen over the course of the next decade.

PART IV

Conclusions

La gota es un modelo de concisión:
todo el universo
encerrado en un punto de agua.
La gota representa el diluvio y la sed.
Es el vasto Amazonas y el gran Océano.
La gota estuvo allí en el principio del mundo.
Es el espejo, el abismo,
la casa de la vida y la fluidez de la muerte.

JOSÉ EMILIO PACHECO

Summary of conceptual and methodological contributions

This dissertation offers a complex systems perspective on water resources management through the operationalization of the WMSES framework (Madrid 2014, Madrid and Giampietro 2015) for the purpose of the integrated assessment of water policies at basin scale. The framework builds on the concept of social-ecological systems, or coupled human-water systems, and a definition of water use that deals with epistemological issues of complexity such as the existence of multiple perceptions of nature, the multi-scale organization of living systems, and circular causality as the main type of relationship maintaining this organization. In order to address the research objective, two relevant conceptual advances have been introduced into the framework alongside several concomitant methodological contributions.

First of all, this is the first implementation of the WMSES at the scale of water basins, either surface or groundwater, that are depicted as open, holarchical and autopoietic SES/WHS. The conceptualization of watersheds as SES is a key development that allows a comprehensive assessment of how social and eco-hydrological systems, and the multi-scale relationships between them, change as a result of the implementation of policies. This assessment requires the combination of different bodies of knowledge and analytical tools, such as human geography, ecological economics, eco-hydrology or institutional analysis. Thereby, I hope it contributes to the new interdisciplinary currents in water science.

I advanced this methodological integration through the link between the analysis of societal metabolism and that of the ecosystem metabolism of water on a spatially explicit basis, using GIS for the integration of an eco-hydrological model in the flow-fund accounting system. By doing so, I could operationalize the WMSES framework, and formalize relationships between the ecosystem and society interfaces, and between their respective structures and water supply and demand. The analysis of the ecosystem metabolism of water was approached through the eco-hydrological processes that control water resource renewability (supply-side sustainability), the impacts caused on ecosystem health (sink-side sustainability) and the boundary concepts of water availability and ecosystem water requirements. This operationalization allows addressing the feedback loop "water supply->societal uses/discharges->impacts on ecosystems->impacts on supply". Thereby, social-ecological patterns of water can be described through the characterization of this loop in WHS, which can be defined through the combination of criteria from the watershed and problemshed perspectives. These criteria used to define the boundaries and analytical levels of the SES/WHS should be made explicit, as well as the mismatches and losses of information associated with the pre-analytical decisions. This type of integrated representation is something that water plans in both case studies lack, because they only apply a watershed criterion in their delimitation of management units. However, the possibility of considering socio-economic criteria is foreseen in the Spanish Instruction for Hydrological Planning, and it has recently been applied in other basins to subdivide groundwater bodies.

In the Tucson basin case study, I also combined water metabolism accounting with the spatial analysis of groundwater management (location of sources, users, and groundwater storage, and impact on aquifer levels and their dependent riparian ecosystems). This combination is particularly suitable for understanding how the metabolic functioning of the system is geographically displayed, and shapes spatially differentiated vulnerabilities and inequity.

In addition, I have made progress in the integration of GIS techniques in MuSIASEM by designing a conceptual data model for data structuring and management in water metabolism studies. This model has been further developed through three logical models adapted to the analytical extents and objectives of the different chapters. The logical models have in turn been implemented in several geodatabases in open reusable formats with the aim of contributing to the transparency and reproducibility of this research.

Second, this is the first application of the WMSES in the appraisal of the outcomes of the implementation of water policies. MuSIASEM is usually employed to assess the sustainability of future pathways related to possible political decisions. However, ex-post analyses of how political decisions have shaped metabolic patterns are not very common. The concept of the holon is particularly useful to this purpose because it embraces the idea of emergent properties as the outcome of both the interactions among parts at lower levels that cannot be obtained by their mere aggregation, and the boundary conditions posed by upper levels. Therefore, the question turns into "What are the cross-holon interactions that are driving the observed metabolic patterns and their associated water management challenges?" In addition, the conceptualization of the holon as a dual physical rate-dependent and a constructed, informational, rate-independent entity enables the bridging of quantitative biophysical and qualitative policy analysis. Following other frameworks for SES that address feedback relationships between societal and ecological systems, the core conceptual contribution of this dissertation is this bridge between water metabolism and water governance.

On a conceptual level, this connection materialized through the following processes: i) the addition of a third axis to the multi-axes holarchic representation of SES, with the *infoshed* referring to the policies and regulations driving metabolic change and mediating relationships between societal and eco-hydrological holons; ii) the formalization of this axis within the general WMSES framework as a boundary area on the societies/ecosystems interface; iii) a discussion of water availability as a normative boundary category that depends on infrastructural, technical, sociocultural and eco-hydrological factors at the same time, and the calculation of which requires the explicit recognition of underlying assumptions; and iv) the development of the concepts of the semiotic process and semantic closure of the water management cycle (Allen and Giampietro 2014, Diaz-Maurin and Kovacic 2015), integrating Hajer's (1995) concepts of problem closure, social accommodation and discursive closure. These checks pose questions that in turn have been used to operationalize the policy assessment criteria of effectiveness, efficacy and pertinence.

On a methodological level, this connection has been operationalized through the combination of quantitative and qualitative analysis tools. Regarding quantitative analyses, three water grammars have been tailored to the specific analytical objectives of the case studies. The grammars have been formalized through different models and statistical sources, and depicted for the integrated analysis of metabolic patterns in dendrograms, radar graphs or tree-icicle visualizations. The integrated analysis of metabolic patterns provides insights into the lower-level socioeconomic drivers of change in the water metabolism, the biophysical outcomes resulting from the implementation of policies, and the trade-offs associated with management decisions. With this latter aim, Chapter 3 presents a scenarios exercise that compares RBMP scenarios with alternative ones. The elaboration of this exercise required a normative definition of the alternative scenarios with different decisions that were biased towards what I aimed at showing. Ideally, these decisions would not have been made by me as an analyst but by stakeholders in participatory processes.

Discourse analysis has been a key tool for understanding the diversity of perceptions about water management and dominant discourses permeating decision making, allowing researchers to tackle the question of the "how and why" of metabolic patterns of water. This question of '"how and why" complements those of "what the system is" and "what the system does", which are normally addressed with MuSIASEM. The production and evolution of hydro-social landscapes is filled with a variegated set of social agents set against each other with changing and more or less acute conflicts and struggles. Fund and flow configurations are invariably filtered by social dreams and fantasies, and are politically managed or reimagined through shifting governance arrangements. The diverse and changing attributes of water, together with the contentious uses, demands and imaginaries surrounding it, are always mediated through political institutions and policy networks and regimes, which include those through which access to or ownership of resources, and the tools for its distribution are organized.

Finally, regarding the post-normal science framework in which MuSIASEM is situated and the more extended transdisciplinary practices, I endeavored to collaborate with stakeholders in both case studies within my time and resource constraints, and some reflections on these experiences are summarized. I hope that the proposed framework contributes to the bridging of some of the current science-policy gaps, such as the need for multi-scale analysis, the targeting of collaboration with practitioners and the opening up of scientific knowledge (Jarvis et al. 2015).

Conclusions about challenges in water governance in case-studies

This dissertation follows the implementation of sustainability objectives in water policies in two water basins in Spain and Arizona. The two areas share similar semi-arid conditions, sun-driven economic models, acute human pressures on water bodies, and techno-managerial water governance models. Both basins face situations in which over-abstraction of resources propelled aquifer degradation as a core problem driving water policies and management strategies. In addition, they also share an ideological background of hydraulic mission (Sauri and del Moral 2001, Molle 2006), culturally anchored for over a century through stout epistemic communities brandishing long-lasting claims such as "not one drop should be lost in the sea", and large engineering works to cope with snowballing water scarcity.

The water policies regulating management in the two case studies are rather dissimilar[46], partly because between one and the other there has been an important evolution in the dominant water management paradigm towards IWRM. The GMA in Arizona was enacted in 1980 in response to major aquifer depletion over the course of previous decades. It delimited management extents based on aquifer limits for the most populated areas, and set management goals for each of them. In the Tucson basin, the management goal is safe yield achievement by 2025, which is calculated as a zero sum between outflows and inflows for the whole basin as a black box. This differs substantially from the European WFD released in 2000 that focusses on the quality of aquatic ecosystems. The directive embraces the principles of IWRM, such as river basins as management units, economic instruments for decision making and public participation in water planning. Management goals are established for every surface and groundwater body as a horizon for the achievement of status, to be restored to purportedly pristine condition (Bouleau and Pont 2015).

[46] Appendix 6 shows a table with a comparison of the main features of both regulations.

Water management in the Andarax river basin appears to be in a situation of institutional lock-in that responds to several entwined external and internal multi-level causes. Regarding external drivers, at an international and European level, the continuous negotiations among contested interests surrounding agricultural production, rural development and ecosystem conservation have been framed by the inclusive discourse of sustainable development. This is reflected in the win-win-win rhetoric of policy goals linking social equity and ecological quality to economic growth. However, agricultural discourses are biased towards the market function of agriculture, whereas water discourses are biased towards ecosystem integrity. At a national level, the principles of the WFD encountered an old institutional inertia managed by powerful coalitions formed by the central government, old RBAs, large agricultural and hydroelectric lobbies, and civil-engineering corporations, which was focused almost exclusively on river regulation and inter-basin transfers. As expected, these coalitions struggled to adapt to the new framework, and in many cases hampered the possibilities of shifting management priorities. At a regional level, significant steps have been taken towards a rigorous normative development of the WFD and the integration within agricultural policies. However, this integration has been pursued through strategical win-win bridges between political agendas, these bridges essentially being based on technological interventions to generate additional resources. In addition, the implementation of the resulting standards is subjected to infringements of the law, not in an incidental but in a structural atmosphere of deviance or non-compliance with legal norms (Sampedro and del Moral 2014), within a substantially waned and unstable water administration in terms of both budgetary allocation and decision-making capacity.

Regarding internal drivers, the Andarax river basin is a genuine complex SES due to its outstanding biophysical, cultural and institutional diversity, which can be observed in a range of evolving hydro-social landscapes. Agriculture is the main driver of change in water metabolism, with very different agricultural metabolic patterns coexisting with, and sometimes competing for, water bodies in different situations of impact. These patterns go from upper rural areas with low-productive agriculture adapted to their ecosystem water metabolism, to intensive techno-boosted greenhouse vegetable production and stock-groundwater-fueled olive monoculture. The city of Almeria is another key player, not only as a major water user and producer, but also through the intricate rural-urban relationships influencing the socioeconomic transition of rural areas from the agricultural to the services sector. The degradation of water bodies responds not only to the entanglement of multiple direct causes, such as an excess of withdrawals during summer periods and wastewater discharges, but also to other long-term processes like the abandonment of traditional agriculture and erosion, lax land planning, and an absence of monitoring of and control over abstractions that adds to the great uncertainty regarding the insufficient knowledge about impacts on aquifers and their dependent systems.

The challenges posed by EO are related to the impossibility of reducing pressures and impacts on water bodies without effectively reducing withdrawals and discharges. This would require the re-addressing of land uses and water rights, the integration of water and land management in a format of comprehensive planning, and, especially, an acute monitoring of pressures and transparency in decisions. In other words, the achievement of EO requires a reconfiguration of the power balance among water users and among different sections of the regional administration. Far from facing up to this conundrum, regional management decisions in Almeria strove for a techno-social fix to attend to both EO and agricultural demands by applying the following strategies: i) restricting the expansion of irrigable land but enabling irrigated land to reach the irrigable ceiling; ii) incrementing the technical efficiency of irrigation; and iii) augmenting the desalination and reclamation capacity. The required infrastructural investment was aided by European funds channeled through several national and regional programs.

Underlying these decisions there is a dominant water discourse that combines deep-ecology justifications and problem structuring with ambiguous efficiency arguments from IWRM biased towards incrementing supply, and with the traditional supply-oriented demands for more infrastructures to cope with "structural deficit". Contesting narratives unveil a social-ecological perception of the livelihood of rural communities, eco-integrative proposals for reorienting the economic model as well as critical claims about the institutional and political performance of water administration bodies. These perceptions are either accommodated through techno-social fixes, prompting coalitions among otherwise contested narratives, or directly rejected as "outside the scope of water management".

The chosen strategies entail important trade-offs that were overlooked in the water planning process. First of all, water accounting in management scenarios anticipated a rebound effect in water use patterns, at the same time as compulsory e-flows were disregarded. This is related to the fact that efficiency increment is deemed a supply-augmentation and not a demand-control measure in the RBMP. Secondly, the significant intensification of energy, and thus monetary, costs associated with desalination was neither accounted for in the economic analysis of the RBMP nor negotiated with farmers taking into account the cost-recovery mandate of the WFD. The problem posed by water was simply solved by increasing the problem posed by energy. Thirdly, the installation of drip irrigation implies an alteration in well-integrated social-ecological patterns in rural areas. Flood irrigation systems are part of the traditional adaptive practices of the Mediterranean region, existing within an integrated management system of surface, subsurface and soil flows. The low technical efficiency of irrigation has represented a buffer when adapting to drought periods in semi-arid areas by increasing efficiency. Water losses due to low technical efficiency are returned to the environment, and benefit third parties when flowing out in lower springs. Therefore, their reduction might lead to important social and ecological impacts that need to be carefully considered. The potential trade-offs of phasing out traditional infrastructures and institutions are emphasized by the communities in question. These communities extend the debate on water management problems from the basic RBMP idea of flow augmentation to more complex ideas about the structural drivers of metabolic change such as demographic ageing, rural exodus and landscape desertification. The long-term social-ecological evolution of water metabolism in these areas challenges the ecosystems integrity goal of the WFD.

At the end of the first water management cycle (2015), the outcomes of the chosen strategies proved highly cost-ineffective in the new context of financial austerity, unraveling the premises under which the RBMP was designed. The great recession from 2010 onwards stalled economic growth and large-scale developments, thus the expansion of demands. In spite of that, progress towards EO is almost inexistent since the RBMP was never implemented at all. Moreover, there is the patent problem of insufficient information, transparency and justification of decisions, as well as of ineffective communication, all of which has been downplayed during the management cycle. As a result, local resistance to implementing measures and fostering cooperation among actors has emerged, alongside a generalized mistrust of the water administration body, which is deemed incapable of dealing with perceived problems.

The Tucson basin has already gone through three management cycles, with the much more significant outcomes resulting from the GMA implementation. The main management strategies are not far removed from those employed in the Andarax basin: new supplies, an improvement in efficiency and non-expansion of irrigable land. However, the way they were applied in the Tucson basin was substantially different, essentially because there was a real commitment to controlling demand and to devoting new supplies to the retrieval of groundwater overdraft. A remarkable attempt at integrating land and water planning was the subjection of new developments to the demonstration of a hundred years of assured water supply. In addition, the compulsory annual reporting of withdrawals and uses provides the ADWR with key water budget information for assessment and planning.

Since the year 2000, there has been an observed decreasing trend in the annual groundwater overdraft that has recently been approaching zero. The tipping point for this shift was the effective alliance between CAP construction and the recharge, storage and recovery system, this alliance eliciting a drastic reconfiguration of water metabolism with a plethora of new water sources. This infrastructural investment was accompanied by a range of new regulations, institutions and cooperative programs among the multiple nodes of a decentralized governance regime.

The municipal sector has been the most adaptive in reducing overdraft by replacing more than half of its groundwater consumption with CAP-recovered water, and by stabilizing its demand through conservation per capita. However, a thorough understanding of the effect of urban development stagnation and the potential effects of the reactivation of the sector would be worthwhile. The expectations of growth for this sector remain unaltered; they have simply been postponed for the next ten years. The agricultural sector drives inter-annual variability in overall water demand and overdraft in the TAMA, mirroring weather and agricultural market vagaries. The partial substitution of groundwater by CAP in lieu is the most vulnerable to droughts in the Colorado basin. What will be the impact of the current Colorado drought episode on the achievement of safe yield is an important question to look at. The Indian Nations are an increasingly important player in the overall water budget and their role in the emerging LTSC market is another issue to be looked at. Finally, mines are causing significant local impacts on aquifers, and their qualitative long-term effects are not fully understood. The technical achievement of safe yield is based on fragile premises by considering Colorado River water as a renewable resource that will continue to fuel the economy without questioning the growth model that is driving snow-balling water scarcity. Uncertainties related to climate change, drought in the Colorado basin and the entangled dynamics of the different sectors need to be thoroughly addressed.

Basin-pooling water accounting conceals an uneven distribution of the technical safe yield achievement. The spatial disconnection between recharge and recovery is obscured by the label of "CAP-recovered", a category that is suppressed in the overdraft equation. This spatial neutrality of groundwater management provides the ADWR with the flexibility to negotiate with regional stakeholders, but at the same time overlooks equity issues regarding the privileged situation of large mining sites and developers that are members of the CAGRD, all of whom can continue to mine groundwater anywhere in the basin. The sub-regional breakdown of the water budget into water accounting areas should enable a better assessment of social-ecological vulnerabilities associated with the continuous decrease of water tables in some areas. Currently, the main proposal to address the spatial inequity in safe yield accounting is to build new infrastructures to bring CAP water to all areas experiencing groundwater table decreases. However, it is important to keep in mind that increasing infrastructural complexity is usually accompanied by a rebound effect in water demand as well as by a reduction of resilience to perturbation such as droughts. A careful cost-effectiveness assessment of alternatives would be worthwhile.

Besides the accepted premise of Colorado River water as a renewable resource, pinpointing a dominant water discourse in the Tucson basin is not easy because the decentralization of decision making makes the power network more leveled than in the Andarax basin. Nevertheless, clearly polarized narratives reflect perceptions surrounding the economic model based on urban growth. These range from developers defending the economic argument of the allocative efficiency of IWRM, to the denouncement of growth as detrimental to local people's quality of life and regional resilience. Water utilities are clearly strategic players in this network and defend the sound techno-managerial expertise of water decisions. In light of the transition to the fourth management cycle for 2010-2020, these contrasting narratives were accommodated through intense regional multi-stakeholder cooperation, participatory processes and grand consensual objectives of water for the present and the future, and for the economy and the environment. However, the economic recession did also significantly impact the ADWR budget and resources, and the fourth MP has accumulated five years of delay and increasing challenges in the achievement of a spatially equal, environmentally sound and durable safe yield in the next decade.

Like most environmental governance regimes, water management in both study sites mirrors the ecological modernization discourse of sustainable development. Nevertheless, the practical reach of IWRM principles has been inchoate or partial. One reason is the dispute with pre-existing values, institutions and coalitions. Another is the double edge of the ambiguity of integration as a discursive strategy that propels narrative coalitions among truly opposing meanings. But the main underlying reason is the limits imposed by the actual impossibility of thinking outside the box of economic growth as the ultimate political goal of our time. These are the limits of sustainable development itself as a global 'grand narrative' to guide political action to face up to the challenges of humanity[47]. Both basins could be considered to be in a situation of overbuilding or social scarcity. In this type of situation, a positive feedback loop is established when the over-commitment of resources generates social-ecological impacts, bringing about new infrastructures that fuel growth and demand, in turn generating new scarcity (Molle 2006). This vicious cycle of artificial scarcity is what the Andalusian government terms "structural deficit", something that cannot be broken by repeating the same courses of action over and over.

I would like to insert a note of caution on efficiency as the new mainstream global discursive strategy for water management. Efficiency can be defined and measured in different ways (such as technical, productive and allocative) and thus its meaning needs to be made explicit. Augmenting technical efficiency (increasing the ratio net/gross resource use) requires the increment of structural complexity and the reduction of adaptive capacity and resilience. Productive efficiency is a synonym of increasing productivity or getting more end-use per unit of resource (lower intensive ratios of liter or kilogram per capita or kilogram). While this is generally celebrated as an avenue for

[47] I am finishing this writing on the same day that global leaders are meeting at the UN Sustainable Development Summit 2015 to discuss and approve the new Sustainable Development Goals. From reading the proposal for these goals, it appears clear that the limitations of sustainable development discussed in this dissertation are reinforced in the new agenda, which will guide global action for the next fifteen years.

reducing resource consumption, careful attention should be paid to offsets in overall demand. Increments in productivity lower the prices of the resource, which in turn fosters new uses. The same thing occurs with allocative efficiency, which demands the assignation of resources to the most profitable activity (more €/liter), this generating new expectations that attract new investors. This is the so-called Jevons paradox, which demonstrates that improvements in efficiency lead to an increase in the structural size of the system in the long run and thus in the overall demand for resources. So far, this paradox has not been refuted in the field of water management, although there is an intense ongoing academic debate with regard to the conditions necessary to avoid rebound effects in the improvement of the technical efficiency of irrigation (Sampedro and del Moral 2014, Berbel et al. 2015). In addition, structural trade-offs of augmenting efficiency are not properly taken into account in water planning. Accountability and evaluation mechanisms to ensure that efficiency, in any of its forms, is a conducive strategy to be used for controlling demand and not for contributing to the scarcity loop, are a clear research and management challenge.

A final general reflection is that the dominant techno-managerial vision on how water should be managed continues to seek, or claims to seek, win-win-win solutions to complex environmental problems. It might be wise to start acknowledging that most of the time these ‘solutions’ end up becoming win-lose-lose realities (Scheidel 2013), either among dimensions of sustainability, either among the members of the same hydrological system or from different ones. Critical evaluations of the trade-offs and outcomes of political strategies are essential in order to foster social learning and improve adaptive capacity. I hope to have contributed to this challenge with the case studies presented. Furthermore, I would like to call for a politically wise recognition of the need to open transdisciplinary debates about when enough is enough (Molle, 2006).

To end this section, I will outline the main lessons learned from what in my opinion works in each region that could contribute to the enhancement of management in the other. I think that Arizona water policy has a lot to learn from the European WFD in terms of more ambitious policy goals, a better territorialization of management boundaries that includes all basins, and more environmentally sound management that could help to deal with emerging challenges surrounding groundwater-dependent ecosystems. Setting management goals at the level of water bodies facilitates a better sub-regional understanding of social-ecological patterns and helps to avoid the flaws of basin-pooling accounting devices. Regarding the Andarax basin, the main positive to be taken from Arizona is clearly the significantly greater trust in water managers and decision makers. From my observations of what takes place there, this trust is built on an effective control and monitoring of withdrawals, compulsory water accounting as a basis for evaluation and learning, the exemplary transparency of public agencies, the existence of accountability mechanisms for decision makers, and the much more effective regional public participation. Finally, I think that both policies could benefit from a vision of social-ecological systems to address problem solving in a more integrated, complex and hopefully useful way.

Reflections on the inter and transdisciplinary experiences in this research process

In my view, interdisciplinarity is a pathway that will take many years to be walked. Despite having strived to integrate different analytical frameworks and tools from different research disciplines, it is obvious that I am not an expert in all of them or even in any of them. Having a multi-disciplinary educational background, it is relatively easy for me to understand different scientific narratives and constructions about a reality, and I feel comfortable navigating, translating and finding relationships among them. However, there are times when I clearly lose methodological accuracy and enter into fuzzy areas of eclecticism. Therefore, my aim is to work within truly interdisciplinary teams in which can be found effective avenues for dialogue among different areas of expertise and epistemological backgrounds.

My experience within the group of students in the SWAN project has provided some lessons for future projects regarding the challenges involved in interdisciplinary work, which are not that far removed from those involved in the work of any group of diverse humans trying to achieve objectives collaboratively. First of all, it is important to say that interdisciplinarity within a common framework with explicit analytical rules, like societal metabolism or ecosystem services, is much less challenging than if each of the team members apply a different framework. This is because integrating methodologies is easier than integrating mental constructions and epistemologies from the realism-constructivism continuum. In the case of the SWAN group, each of us was applying its own framework.

In this type of interdisciplinary group, the process of conceptual modeling, and consequently its outcomes, certainly follows different avenues depending on which are the backgrounds sitting at the table and who leads the discussion. Because the group was more weighted towards quantitative approaches, at the beginning we found ourselves more comfortable talking about the integration of variables and models than about power or conflicts, which took longer to be understood. Because each concept meant something different to each of us, discussions about consensual definition could take hours, sometimes with unsatisfactory results. There is a degree of irreducible incommensurability that has to be accepted and, I would say, generously embraced. Indeed, the points of disagreement were those that pushed discussions towards more thoughtful and creative areas.

After four months, we had failed to develop an integrated conceptual framework, basically because of these irreducible epistemological differences. Our decision was then to opt for a common case-study, in which we aimed to generate feedback from the abstract to the empirical and then back to the abstract. The outcomes of that decision will be seen when we complete the process in 2016, but they will surely be different from those we had imagined, because the group has evolved. Academic groups change all the time, with new people coming in and others leaving, and each researcher having individual personal interests and constraints. Therefore setting common goals that require long-term thinking and collaboration can be daunting.

The question of our role as researchers is at the core of the difficulty in moving towards transdisciplinary collaboration with actors outside the academic arena. There is a challenging balance to be found between being consistent with your individual interests and making your results understandable, useful and ready for actual use by stakeholders. Furthermore, there is a clear tension involved in working on real-world problems and using the results to produce cutting edge scientific publications in top ranking journals, because the academic world is to a great extent disconnected from societal needs. Participation processes are complex, difficult to arrange and often frustrating. Proper facilitation is essential in order to ensure leveled participation and deal with micro-political issues. In addition, ethical issues like who will participate and for what reason and purpose should be seriously addressed, acknowledging that participants are not subjects of the study but active members of the process. I would like to add a call for humility in the academic realm when working with people who have their own needs, desires and dreams, the fulfilment of which is not your research objective. Taking these issues seriously when designing research projects requires some pre-funding work, what can be especially challenging in precarious research groups.

Regarding my transdisciplinary experiences in the two case studies, in the Tucson basin interactions with stakeholders were more fruitful than in the Andarax basin because in the former I had a whole research project supporting me from the beginning. In addition, the culture of dialogue and cooperation in the USA is much more intense and extended among practitioners. Stakeholders were more open to attending meetings, discussing questions and giving me feedback on my work there. Spain's poor deliberative culture hampers a more meaningful collaboration. In general, I experienced difficulties in explaining complex concepts to non-academics and trying to bridge abstract theoretical knowledge and day-to-day problem-solving empirical knowledge. In both case studies, I conducted exercises of quantifying indicators and multi-criteria analysis of sustainability (Appendices 3 and 5). This is something that practitioners on both study sites considered useful to their work. However, the outcomes of these processes were not those expected due to a lack of resources, a lack of experience in facilitation and/or timing constraints. Therefore, very demanding activities did not produce publishable academic results, but they definitely gave me a very thorough perspective on what was happening.

In conclusion, despite the many challenges and flaws of my transdisciplinary endeavors in this research, it has been an extraordinary mind-opening experience that has reinforced my determination to make science useful for the solving of real-life problems. My impression is that I have simply opened small windows onto an immense ocean, and that the long voyage of discovery will require commitment and research funding. Janice Dickinson from the Cornell Ornithology Laboratory asked during the discussion at a SWAN project conference, "By becoming a researcher without a specialty, how do you expect to get a job in the academic market?" I answered that the valuing of inter- and transdisciplinary expertise might provide the only chance we have of coping with environmental problems.

Outlook for future research

Future research on the Water Metabolism of Social-Ecological Systems

The WMSES is a very recent analytical framework that has not yet been sufficiently tested. Being semantically open provides the framework with flexibility and robustness, as well as adaptability to new developments, but at the same time requires an effort for a minimum degree of methodological normalization. There is still a need for coordinated case studies in the future in order to move towards this standardization.

An avenue opened in this dissertation that still needs to be developed significantly is the integration of eco-hydrology into MuSIASEM accounting on a spatially explicit basis. BalanceMed allows the splitting of productive and non-productive soil water (transpiration and evaporation), but does not yet deal with other relevant processes such as erosion or water pollution. Other integrative models, like SWAT or WIMMed, could contribute in this sense. Some questions derived from the modeling explained in Chapter 2 involve the exploration of the following issues: *the combined effect of climate change and drought periods, of the collapse of traditional agricultural production and of land-cover evolution on water funds and aquatic systems; or the impacts on the aquifers and dependent systems of the improvement of irrigation efficiency*. These questions can be approached through scenario building, integrating eco-hydrological forecasting, and MuSIASEM water-energy-land-food nexus assessment.

The integrated spatial analysis of societal and ecosystem metabolic patterns of water is to be further explored. Regarding ecosystems as priority criteria for the establishment of focal analytical holons, I think that water in Europe provides a particularly suitable arena in which to advance in this direction because of the systems for the monitoring of ecological integrity of water bodies. From a problemshed perspective, analysis at lower eco-hydrological levels than the water could be integrated with that of rural systems that has been well developed using MuSIASEM. This type of connection could enable accurate assessments of the desirability, viability and feasibility of metabolic patterns. The connection of metabolic analysis at higher grains to water governance would deal with the challenge of upscaling to the basin level. *Which is the suitable scale for defining accurate social-ecological patterns of water metabolism? How should the spatial relations among social-ecological patterns of water be characterized? How can the analysis of rural systems and of water metabolism be integrated on a spatially explicit basis? How can this analysis be scaled up to generate useful information for water planning?*

Because the WMSES is a complex theoretical framework, there is still a need for the proper operationalization of some fuzzy conceptual areas. One of these areas is the impredicative definition of water resources through the identification of both relevant attributes and the range of useful values for those attributes. As I was working with normative water data, I assumed that those flows were supplied in desirable conditions, and the approach followed was a top-down disaggregation of total water demand for different sectors. However, other forms of normative definition of useful water resources can be explored, for instance through public participation. This would enable a bottom-up definition of water flows that could, for example, be adapted to a more accurate definition of societal functions or societal needs, and then contrasted with official water-planning definitions of flows. *What are the useful characteristics of water according to water users? What is the desirable quality, timing of supply and location of water? How can water flows and their services based on these attributes be defined? What are the desirable flows that current water management does not supply?* Another interesting conceptual area to be explored is the analysis of non-productive societal uses of water funds, which is being developed in studies of cultural ecosystem services. This would facilitate, for instance, a move towards more complex definitions of water productivity that incorporate aesthetic values that are core to the current shift towards service economies in high mountain rural areas. *How can non-consumptive societal uses of water funds be identified, qualified and quantified? Does the ecosystem services framework offer useful methodological approaches for this purpose? What is the "value" of water funds?*

Regarding the application of the framework to the assessment of water management strategies, I think that the standardization of methodologies for appraising each typology of strategy (supply augmentation, improvement of efficiencies, growth control, etc.) could enable a better understanding of their interplay when observing outcomes. I think that the MuSIASEM Sudoku-effect could be very useful for building robust frames for an integrated assessment of this interplay that could be tailored to the specificities of policies and regional management and applied to both an anticipatory and an ex-post analysis of trade-offs and outcomes. *Can the Sudoku effect help to dissect the effects of multiple overlaid management strategies?* The ability to answer this question requires the resolution of a prior issue, which is, *How can water accounting in water planning be arranged to allow this assessment?*

Finally, I think that the framework still needs a lot of "translation work" in order to be useful in participatory processes. The heavy conceptual load requires more effective means of communication and the tools for integrated analysis need useful visualizations that are accessible to non-academics. *How can metabolic patterns be visualized in order to facilitate transdisciplinary discussions?* I think that GIS visual tools offer clear advantages in the facilitation of common understanding of environmental problems and thus have a promising future in metabolic studies.

Future research on water governance

Within the SWAN project, the team from the University of Seville opened a new research line around data, information and knowledge for water governance in the networked society that, in my opinion, goes straight to the heart of some important challenges in the field. Some of the research questions that have been raised are the following: *What are the conditions for deliberative mechanisms in water planning necessary to ensure more leveled participation and decision making? Can ICTs play a role in improving the democratic quality of decision making in water resources management?* In addition, progress is required in integrated water information systems, open water-data and visualization platforms. As discussed in this dissertation, transparency in water information is a core issue not only in Spain, but also in many other countries, partly because of the traditional inertia of engineers and water managers who think that water information is too complex to be understood by non-technicians. This era of "the guardians of the truth" is over, and water administration bodies are slowly moving towards more open information standards. Citizens' organizations play a key role in controlling the quality of the information used for making decisions and evaluating their outcomes. Improving the quality and accessibility to data can galvanize progress towards an integrated assessment of water governance.

The emerging practices of citizen science are very promising for a push in this direction, through collaborative scientific projects involving practitioners, stakeholders, communities, activists or the general public. The effective inclusion of non-academics in the research process is not only creating unprecedented opportunities for the scaling up of research by, for example, facilitating the application of big-data analysis techniques, but is also opening new avenues for transdisciplinary dialogue and external quality control of the research process. *How can citizen science help to bridge science-policy* *gaps in water governance?*

Regarding discourse analysis, I am aware that the methodology I used in this research was not the most rigorous considering the recent developments in specific software like Atlas.ti and Envivo, and that great improvements can be made in this sense. A particular research pathway that I would like to explore in near future is the analysis of the use of social media in environmental conflicts or activist campaigns, through a combination of quantitative network analysis and discourse analysis. I am already involved in a collaborative research project that aims to answer the question *What kind of social capital do social networks reinforce?*

Finally, there are two important black boxes in this dissertation that I hope to open in the future: institutions and power. Even if they were mentioned and recognized as essential for the shaping of social-ecological relations, I specifically addressed neither institutional arrangements nor power relations, partly because I lack the educational background to do so. I think that a huge challenge, not only in water governance but also in most public realms right now, is the effective scaling up of citizen participation. Because participation usually works at local levels around common resource management, but ICTs and the Internet have opened up opportunities for improving democratic management and decision making at all levels, the following questions are yet to be responded: *What kinds of institutional arrangements can make bottom-up participation effective and improve the legitimacy of water management decisions? How could an open multi-scale social-ecological governance system be envisaged? Could such a system help to overcome current post-political regimes or would it instead reinforce them?*

CONCLUSIONES

Resumen de contribuciones conceptuales y metodológicas

Esta tesis ofrece una perspectiva de sistemas complejos sobre la gestión del agua a través de la operacionalización del marco de análisis WMSES (Madrid 2014, Madrid and Giampietro 2015) para la evaluación integrada de políticas del agua a escala de cuenca. Este marco se basa en el concepto de sistema socio-ecológico, o sistema socio-hidrológico, así como en una definición de usos del agua que responde a los retos epistemológicos de la complejidad como son la existencia de múltiples percepciones sobre la naturaleza, la organización multi-escalar de los sistemas vivos o la causalidad circular como el principal tipo de relación que mantiene dicha organización. Para abordar el objetivo de investigación se introducen dos avances conceptuales relevantes en este marco, así como varias contribuciones metodológicas asociadas.

En primer lugar, esta es la primera implementación de este marco teórico a la escala de cuencas hidrográficas, ya sean superficiales o subterráneas, que son representadas como sistemas socio-ecológicos abiertos, holárquicos y autopoiéticos. Esta representación de la cuenca como sistema socio-ecológico es una propuesta conceptual clave en esta tesis, que requiere la combinación de diferentes áreas de conocimiento y herramientas de análisis tales como la geografía humana, la economía ecológica, la eco-hidrología o el análisis institucional. De esta forma espero contribuir a las nuevas corrientes interdisciplinares en investigación del agua.

En esta tesis he avanzado esta integración metodológica ligando el análisis del metabolismo social y ecosistémico del agua de manera espacialmente explícita, a través del uso de SIGs para la integración de un modelo eco-hidrológico en el sistema de contabilidad de flujos y fondos de MuSIASEM. De esta forma pude operacionalizar el marco conceptual del metabolismo hídrico, formalizando relaciones cuantitativas en las interfaces sociedades-ecosistemas, así como entre sus respectivas estructuras y la demanda y provisión de agua. Para el objetivo y escala de análisis de esta tesis, se propone una aproximación al metabolismo hídrico de los ecosistemas a través del análisis de los procesos eco-hidrológicos que determinan la provisión de recursos hídricos, los impactos causados sobre la salud de los ecosistemas, y los conceptos frontera de disponibilidad del agua y requerimientos hídricos de los ecosistemas. Esta operacionalización permite analizar la retroalimentación entre 'provisión de agua -> usos/vertidos -> impactos sobre los ecosistemas -> impactos sobre la provisión'. Caracterizando estos links se pueden describir patrones socio-ecológicos de metabolismo hídrico en sistemas hidro-sociales, los cuales se pueden definir a través de diferentes criterios que combinen la 'cuenca del agua' con la 'cuenca de problemas'. Los criterios para definir los límites y niveles analíticos del sistema tienen que hacerse explícitos, así como las incompatibilidades resultantes entre diferentes tipologías de límites de gestión y las consecuentes pérdidas de información relevante asociadas a estas decisiones pre-analíticas. La planificación hidrológica en los dos casos de estudio de esta tesis carece de esta visión integrada puesto que solamente aplican criterios hidrológicos para delimitar las unidades de gestión. La Instrucción Española de Planificación Hidrológica prevé la posibilidad de incorporar otros criterios además de los hidrogeológicos, lo cual se ha aplicado ya para subdividir las masas de agua subterránea en algunas cuencas españolas.

En el caso de estudio de la cuenca de Tucson, combiné el análisis del metabolismo hídrico con el análisis espacial de la gestión del agua subterránea (localización de fuentes, usuarios, almacenamiento de agua subterránea e impacto sobre niveles de acuíferos y ecosistemas de rivera dependientes). Esta combinación es particularmente útil para entender cómo se despliega geográficamente el funcionamiento metabólico del sistema y moldea diferentes vulnerabilidades e inequidad espacial.

También he avanzado la integración de las técnicas de SIG en MuSIASEM a través del diseño de un modelo conceptual para la estructuración y gestión de datos para el análisis del metabolismo hídrico. Este modelo lo he aplicado después a dos modelos lógicos adaptados a las particularidades de cada caso de estudio, implementados a su vez en varias bases de datos geográficas con formatos abiertos con el objetivo de contribuir a la transparencia y reproducibilidad de esta investigación.

En segundo lugar, esta es la primera aplicación del marco teórico del metabolismo hídrico para la evaluación de resultados de la planificación hidrológica. MuSIASEM se ha aplicado comúnmente para acompañar un proceso de decisión entre diferentes alternativas de gestión, evaluando la sostenibilidad de posibles escenarios. Sin embargo, análisis de cómo han influido las decisiones políticas en la evolución de patrones metabólicos no son tan abundantes. El concepto de holon es especialmente útil en este sentido, pues introduce la idea de propiedades emergentes como resultado de las interacciones entre las partes del sistema en niveles inferiores, que no se puede predecir por mera agregación de las mismas, y de las condiciones de contorno impuestas por niveles superiores. De esta forma, la cuestión relevante es cuáles son las interacciones entre holons que conducen a los patrones metabólicos observados y los retos de gestión del agua asociados a dichos patrones. Además, la conceptualización de un holon como algo dual que es a la vez material, dominado por leyes físicas, y construido y narrado a través de la creación de significado, facilita ligar el análisis biofísico cuantitativo y el análisis cualitativo de políticas del agua. Siguiendo los marcos de análisis de sistemas socio-ecológicos que abordan retroalimentaciones entre sistemas sociales y ecológicos, la principal contribución conceptual de esta disertación es ese puente entre el metabolismo hídrico y la gobernanza del agua.

A nivel conceptual, esta conexión se materializa a través de: i) un nuevo eje en la representación holárquica de los socio-ecosistemas referido a la 'cuenca de información', esto es, a las políticas y regulaciones que actúan como motor de cambio metabólico y median las relaciones entre holons sociales y eco-hidrológicos; ii) la formalización de este eje en el marco de análisis general como un área en la interfaz sociedades/ecosistemas; iii) una discusión sobre la disponibilidad del agua como una categoría frontera normativa que depende a la vez de factores infraestructurales, técnicos, socio-culturales y eco-hidrológicos, y cuyo cálculo tiene que hacerse explícito reconociendo las asunciones que hay en el mismo; iv) el concepto de proceso semiótico y cierre semántico del ciclo de gestión del agua (Allen y Giampietro 2014, Diaz-Maurin y Kovacic 2015), integrando a su vez los conceptos de cierre del problema, acomodación social y cierre discursivo de Hajer (1995). Estos conceptos plantean cuestiones que a su vez las aplico para operacionalizar lo criterios de evaluación de políticas públicas de eficacia, eficiencia y pertinencia.

A nivel metodológico, esta conexión se operacionaliza a través de la integración de herramientas de análisis cuantitativo y cualitativo. Los análisis cuantitativos se han estructurado a través del desarrollo de gramáticas específicas para los objetivos de análisis de cada caso de estudio. Éstas se han formalizado con distintos modelos y fuentes estadísticas de datos y representadas para el análisis integrado de patrones metabólicos en dendrogramas, gráficos de araña y una visualización en árbol tipo Icicle. Este análisis integrado permite profundizar en los factores socio-económicos que condicionan la transformación del metabolismo hídrico, así como en el impacto biofísico de la implementación de políticas públicas y en los costes asociados a las decisiones de gestión. Con este último objetivo, el Capítulo 3 aborda un ejercicio que compara los escenarios de la planificación hidrológica con otros escenarios alternativos establecidos en base a decisiones diferentes que están sesgadas respecto a lo que pretendía mostrar. Idealmente este tipo de decisiones tendrían que tomarlas actores sociales en procesos participativos.

El análisis del discurso ha sido una herramienta fundamental para entender la diversidad de percepciones sobre gestión del agua y los discursos dominantes que permean las decisiones, permitiendo abordar la cuestión del "cómo y por qué" de los patrones de uso del agua. Esta cuestión complementa otras que se abordan normalmente en MuSIASEM: "qué es el sistema" y "qué hace el sistema". La producción y evolución de paisajes hidro-sociales está repleta de una gran variedad de actores sociales, enfrentados entre ellos y con conflictos y disputas cambiantes más o menos afilados. Las configuraciones de flujos y fondos están invariablemente filtradas por los sueños y fantasías sociales que son gestionados políticamente o re-imaginados a través de regímenes de gobernanza en constante evolución. La diversidad de atributos cambiantes del agua, junto con sus usos contenciosos, demandas e imaginarios a su alrededor están siempre mediados por instituciones y redes políticas, que incluyen aquellos a través de los cuales se organiza el acceso y la propiedad de los recursos y las herramientas para su distribución.

Finalmente, con respecto al marco de la ciencia post-normal en el que MuSIASEM se sitúa, y más extensamente a las prácticas transdisciplinares, he realizado un esfuerzo en colaborar con actores locales en los dos casos de estudio, dentro de mis límites de tiempo y recursos. Más adelante incluyo algunas reflexiones sobre estas experiencias. Espero que el marco propuesto pueda contribuir a minorar algunas de las brechas que existen hoy día entre la ciencia y la política, como la necesidad de análisis multi-escalares, que busquen la colaboración con gestores y que abran el conocimiento científico más allá del ámbito académico (Jarvis et al. 2015).

Conclusiones sobre los retos en la gobernanza del agua en los casos de estudio

Esta tesis realiza un seguimiento a la implementación de objetivos de sostenibilidad en políticas de agua en dos cuencas en España y Arizona. Ambas áreas comparten un clima semi-árido, modelos económicos en torno al sol que generan presiones agudas sobre las masas de agua, y modelos de gobernanza tecno-gerenciales. Además, ambas cuencas comparten situaciones de sobreexplotación de recursos hídricos que han conducido a la degradación de los acuíferos como problema fundamental al que la política de aguas y las estrategias de gestión intentan responder. Otra característica común en ambas regiones es una cultura ideológica de paradigma o misión hidráulica (Sauri y del Moral 2001, Molle 2006), anclada durante más de un siglo por firmes comunidades epistémicas abanderando expresiones de tipo ″ninguna gota de río perdida en el mar″, y con grandes infraestructuras hidráulicas como única solución a una escasez de agua en continuo aumento.

A pesar de estas características similares, las políticas de aguas que regulan la gestión en ambos casos de estudio son muy diferentes[48], en parte porque entre ambas hubo una importante evolución en los paradigmas de gestión dominante hacia la Gestión Integrada de Recursos Hídricos. El Acta de Gestión del Agua Subterránea en Arizona se aprobó en 1980 en respuesta a la sobreexplotación de acuíferos en décadas anteriores. El Acta estableció el ámbito de la gestión en torno a los límites de acuíferos en las zonas más pobladas y un objetivo de gestión para cada una de ellas. En la cuenca de Tucson, el objetivo es alcanzar la extracción segura para el año 2025, calculada como la suma cero entre flujos entrantes y salientes de la cuenca entera entendida como una caja negra. Esto difiere sustancialmente de la Directiva Marco del Agua en Europa

[48] El Apéndice 6 muestra una tabla comparativa de algunas características de ambas políticas.

aprobada en el año 2000, que se enfoca en la calidad de los ecosistemas acuáticos. La directiva abraza los principios de la gestión integrada de los recursos hídricos (GIRH) como son la cuenca hidrográfica como unidad de gestión, los criterios económicos como prioritarios para la toma de decisiones y la participación pública en el proceso de planificación. Los objetivos de gestión se establecen para cada masa de agua superficial y subterránea de manera similar: como horizontes de recuperación del estado de la masas de agua a unas supuestas buenas condiciones de referencia (Bouleau and Pont 2015).

La gestión del agua en la cuenca del Andarax se encuentra en una cierta situación de bloqueo institucional que responde a varios factores tanto externos como internos entrelazados a diferentes escalas. En lo que se refiere a los factores externos, las continuas negociaciones a nivel europeo entre múltiples intereses enfrentados en producción agraria, desarrollo rural y conservación de ecosistemas se enmarcan en el discurso inclusivo del desarrollo sostenible. Esto se refleja en la retórica gana-gana-gana de los objetivos políticos que ligan la equidad social y la calidad ecológica al crecimiento económico. Sin embargo, los discursos en agricultura están sesgados hacia la función de mercado de la misma, mientras que en agua lo están hacia la integridad de los ecosistemas. A nivel nacional, los principios de la Directiva Marco encontraron una inercia institucional antigua, gestionada por fuertes coaliciones entre el gobierno central, las Confederaciones Hidrográficas, grandes grupos de presión de intereses agrícolas e hidroeléctricos y empresas de ingeniería y construcción, enfocados casi exclusivamente en la regulación superficial y las transferencias entre cuencas. Como era de esperar, estas coaliciones han puesto resistencias para adaptarse al nuevo marco regulador y en muchos casos han limitado las posibilidades de cambiar las prioridades de gestión. A nivel regional, se llevaron a cabo esfuerzos significativos en una trasposición de la normativa Europea rigurosa y en la integración dentro de las políticas agrarias. Sin embargo, esta integración se ha promovido a través de puentes estratégicos gana-gana entre agendas políticas, basados fundamentalmente en intervenciones tecnológicas para generar recursos adicionales. Además, la implementación de estas agendas se ven sometidas a infracciones continuas de las normas, en una atmósfera no incidental sino más bien estructural de desviación o incumplimiento de leyes (Sampedro and del Moral 2014), con una administración del agua notablemente debilitada e inestable, tanto en presupuesto como en capacidad de decisión.

En lo que se refiere a los factores internos, la cuenca del río Andarax es un genuino y complejo sistema socio-ecológico debido a su espectacular diversidad biofísica, cultural e institucional, la cual se observa en una variedad de paisajes hidro-sociales en evolución. La agricultura es el principal sector consumidor de agua con diferentes patrones metabólicos coexistiendo con, y a veces compitiendo por, masas de agua en diferentes situaciones de impacto. Desde zonas rurales de alta montaña con agricultura de baja productividad adaptada al metabolismo hídrico de sus ecosistemas, a cultivos intensivos en invernaderos tecnológicamente sostenidos y al monocultivo de olivar intensivo alimentado con stocks de aguas subterráneas no renovables. La ciudad de Almería es también un actor importante en el metabolismo hídrico de la cuenca, no sólo como consumidor y productor de recursos hídricos, sino también a través de las relaciones rural-urbano que influencian la transición socio-ecológica en áreas rurales hacia el sector servicios. La degradación de las masas de agua responde al entrecruzamiento de varias causas directas como el exceso de extracciones en períodos de verano o los vertidos de aguas residuales no tratadas, pero también a procesos estructurales de largo recorrido como el abandono agrícola y la erosión, una planificación territorial bastante laxa, la ausencia de monitorización y control sobre las extracciones que se añaden a la gran incertidumbre asociada a la alteración de los acuíferos y sistemas dependientes.

Los retos que plantean los objetivos ambientales de la Directiva están relacionados con la imposibilidad de reducir las presiones e impactos sobre las masas de agua sin reducir las extracciones y los vertidos. Esto requeriría una reasignación de usos del suelo y concesiones de agua, integrando la gestión hidrológica y territorial en una planificación integrada y, especialmente, una monitorización efectiva de las presiones existentes y transparencia en las decisiones. En otras palabras, estos retos requieren una reconfiguración del balance de poder entre usuarios del agua y entre secciones de la administración regional. Lejos de enfrentarlos, las decisiones regionales apostaron por un ajuste tecno-social entre objetivos ambientales y atención a nuevas demandas agrícolas a través de: i) la restricción de la expansión del regadío al techo impuesto por lo que estaba catalogado como tierra irrigable; ii) el aumento de la eficiencia de riego; y iii) aumentar la desalinización y la reutilización. La inversión infraestructural necesaria fue subvencionada con fondos europeos canalizados a través de diversos programas nacionales y regionales.

Detrás de estas decisiones se encuentra un discurso dominante que combina justificaciones y diagnóstico de problemas de ecología profunda, con argumentos ambiguos de eficiencia de la GIRH sesgados hacia el incremento de la oferta, y con declaraciones tradicionales de gestión de la oferta a través de infraestructuras para resolver el “déficit estructural”. Narrativas alternativas desvelan percepciones en torno a la sostenibilidad socio-ecológica de la comunidad rural, propuestas eco-integradoras para reorientar el modelo económico, así como afirmaciones críticas sobre el funcionamiento político e institucional de la administración hídrica. Estas percepciones o bien son acomodadas a través de los mencionados ajustes tecno-sociales (desalinización, riego por goteo), favoreciendo coaliciones entre narrativas antagonistas, o son directamente ignoradas y catalogadas como “fuera del ámbito de la gestión del agua”.

Las estrategias elegidas implican costes importantes que no han sido contemplados durante el proceso de planificación. En primer lugar, la contabilidad del agua en los escenarios anticipaba un efecto rebote sobre en el uso del agua en la agricultura, a la vez que los caudales ambientales quedaban desatendidos. Esto está relacionado con el hecho de que el aumento de la eficiencia se considera una medida de incremento de la oferta y no de control de la demanda en la planificación hidrológica andaluza. En segundo lugar, la introducción de la desalinización para la agricultura conlleva una intensificación importante en el coste energético del abastecimiento de agua, y por tanto en el monetario. Esto no ha sido considerado en el análisis económico del plan, ni negociado con los agricultores que debían pagar por los costes de la misma. El problema del agua se resuelve simplemente empeorando el problema de la energía. En tercer lugar, la instalación del riego por goteo plantea una alteración de patrones socio-ecológicos bien integrados en zonas rurales. Los sistemas de irrigación por manta en zonas semi-áridas han supuesto buffers de adaptación en períodos de sequía a través del aumento de la eficiencia. Las pérdidas por baja eficiencia son retornos al sistema que benefician a terceras partes cuando surgen por manantiales a menor cota. Por lo tanto, su reducción puede conllevar impactos ecológicos y sociales que deberían ser analizados con detenimiento. Estas comunidades enfatizan los costes potenciales de desfasar las prácticas e instituciones locales tradicionales, ampliando el debate sobre los problemas del agua desde la ampliación de los flujos a los factores estructurales de cambio metabólico como el envejecimiento de la población, el éxodo rural y la desertificación del paisaje. La larga evolución socio-ecológica del metabolismo hídrico en estas áreas reta al objetivo de integridad ecológica de la Directiva Marco del Agua.

Al final del primer ciclo de gestión (2015), los resultados obtenidos a través de las mencionadas estrategias han sido bastante coste-inefectivos en el nuevo contexto de austeridad financiera, desmontando las asunciones sobre las que el plan fue diseñado. La recesión a partir del año 2010 estancó el crecimiento económico y las grandes intervenciones. Sin embargo, el progreso hacia los objetivos ambientales ha sido prácticamente inexistente puesto que el plan apenas se ha implementado. Por otra parte, existe un problema patente de insuficiente información, transparencia y justificación de las decisiones tomadas, además de comunicación poco efectiva, que se ha dejado de lado durante el ciclo de planificación. Como resultado, han emergido resistencias locales a aplicar las medidas y promover la cooperación entre grupos sociales, además de una generalizada falta de confianza hacia la administración del agua que es considerada incapaz de resolver los problemas.

La cuenca de Tucson ha atravesado ya tres ciclos de gestión con resultados mucho más significativos de la implementación de Ley de Gestión del Agua Subterránea. Los principales mecanismos de gestión no están muy lejos de los del Andarax: aumentar la oferta, mejorar la eficiencia y no expandir el regadío. Sin embargo, el despliegue de estas estrategias se ha realizado de forma notablemente diferente, fundamentalmente porque ha existido una voluntad real de control de la demanda a través de la limitación del crecimiento y de prácticas de conservación, así como del uso de los nuevos recursos para acabar con la sobreexplotación de los acuíferos. Un notable esfuerzo por integrar la gestión del agua y la ordenación del territorio fue la subordinación de la construcción de nuevas urbanizaciones a la demostración de cien años de abastecimiento de agua asegurado. Además, la obligatoriedad de reportar las extracciones y consumos anuales genera una información muy valiosa para la planificación y evaluación del progreso hacia los objetivos políticos.

Desde el año 2000 se observa una tendencia decreciente en la tasa de sobreexplotación anual que está aproximándose a cero. La alianza efectiva entre la construcción del CAP y el sistema de recarga, almacenamiento y recuperación de los nuevos recursos supuso un claro punto de inflexión que provocó una reconfiguración drástica del metabolismo hídrico con una batería de nuevas fuentes de agua. Esta inversión infraestructural fue acompañada por una serie de nuevas regulaciones, instituciones y programas de cooperación ente los múltiples nodos de una red de gobernanza descentralizada.

El sector municipal ha sido el más adaptativo en la reducción de la sobreexplotación sustituyendo más de la mitad de su consumo de agua subterránea por agua recuperada del CAP y estabilizando su demanda a través de esfuerzos en conservación por habitante. Sin embargo, sería oportuno comprender en profundidad cuál es el efecto del estancamiento del desarrollo urbano sobre dicha estabilización y cuáles son los impactos potenciales de su reactivación en los próximos años. Las perspectivas de crecimiento por parte de este sector no han cambiado, simplemente se han pospuesto a los próximos años. El sector agrario es el que condiciona la variabilidad interanual en la demanda y la sobreexplotación, en función de la variabilidad climática y la deriva de los mercados. La sustitución parcial del bombeo por agua del CAP es la más vulnerable a un episodio de sequía en el Colorado. Una cuestión importante es el impacto que el episodio actual de sequía en la cuenca del Colorado va a tener sobre el alcance técnico de la extracción segura. Las Naciones Indias son un actor cada vez más importante en el balance de agua y su papel dentro del mercado de créditos de agua es otro tema a analizar. Finalmente, las minas están causando impactos locales sobre los acuíferos importantes cuyos efectos cualitativos a largo plazo no se conocen. El alcance técnico de la extracción segura se basa en asunciones frágiles al considerar que el agua del Río Colorado es un recurso renovable que continuará mantieniendo la economía sin cuestionar el actual modelo de crecimiento que genera escasez continua de agua. Las incertidumbres relacionadas con el cambio climático, la sequía en el Colorado y las dinámicas entrelazadas de los diferentes sectores deberían ser abordadas en profundidad.

El sistema de contabilidad del agua de tipo caja negra corre un velo sobre la distribución desigual del alcance técnico de la extracción segura del acuífero. La desconexión espacial entre la recarga y la recuperación queda difuminada bajo la etiqueta de CAP-recuperada, categoría que es eliminada de la ecuación de cálculo de la sobreexplotación. Esta neutralidad espacial de la gestión del agua subterránea permite al Departamento de Recursos Hídricos de Arizona contar con cierta flexibilidad para negociar con los actores regionales, pero también pasar por alto el debate sobre inequidad respecto a la situación privilegiada de las grandes minas y de los promotores y constructores urbanos que pueden seguir sobreexplotando los acuíferos en cualquier punto de la cuenca. La regionalización espacial del balance hídrico en varias sub-áreas de contabilidad debería permitir una mejor evaluación de la vulnerabilidad socio-ecológica asociada a la bajada continua del nivel freático. Por el momento, la principal propuesta para dar respuesta a esta inquidad espacial es construir más infraestructura para llevar agua del CAP a las zonas donde los niveles siguen bajando. Una consideración importante a esta estrategia es que el aumento de la complejidad infraestructural suele ir acompañado de efecto rebote en la demanda de agua así como de una disminución de la resiliencia ante perturabaciones como las sequías. Una evaluación cuidadosa del coste-eficacia de otras alternativas sería aconsejable.

Aparte de la premisa aceptada de que el agua del Río Colorado es un recurso renovable, no es fácil señalar un discurso dominante en la cuenca de Tucson puesto que la descentralización en la toma de decisiones hace que las relaciones de poder estén algo más niveladas que en el Andarax. Sin embargo, narrativas claramente polarizadas reflejan percepciones contrastantes respecto al modelo económico basado en el crecimiento urbano. Desde los promotores defendiendo el argumento del GIRH de eficiencia económica en la asignación de recursos, hasta denuncias contundentes del crecimiento como dañino para la calidad de vida de los habitantes de la cuenca y la resiliencia regional. Las empresas de abastecimiento urbano son actores estratégicos en esta red, defendiendo que la gestión se base en la racionalidad y experiencia técnica. A la luz del cuarto ciclo de gestión 2010-2020, estás narrativas divergentes fueron acomodadas a través de varios acuerdos de cooperación, intensos procesos participativos y objetivos políticos amplios consensuados, con agua para el presente y para el futuro, para la economía y para el medioambiente. Sin embargo, la recesión económica también impactó de manera significativa al presupuesto y los recursos de la administración del agua en Arizona, y el cuarto plan de gestión acumula cinco años de retraso y retos crecientes para alcanzar una extracción segura en la próxima década que sea espacialmente equitativa, ecológicamente sostenible y perdurable en el tiempo.

Como la mayoría de los regímenes de gobernanza ambiental, la gestión del agua en ambos casos de estudio refleja el discurso de la modernización ecológica del desarrollo sostenible. Sin embargo, en la práctica, el alcance de los principios de la GIRH ha sido bastante incipiente o parcial. Una razón de esto es la disputa con los valores, instituciones y coaliciones preexistentes. Otro motivo es el doble filo de la ambigüedad del concepto de integración como estrategia discursiva que provoca coaliciones narrativas entre significados antagonistas. Pero quizás la principal razón subyacente sean los límites de la imposibilidad real de pensar más allá del crecimiento económico como el último objetivo político de nuestro tiempo. Esto es, los límites del desarrollo sostenible como la gran narrativa global para guiar la acción política capaz de resolver los restos de la humanidad[49]. Las dos cuencas estudiadas se encuentran en una situación de sobre-construcción o escasez social. Estos conceptos hacen referencia al establecimiento de un círculo de retroalimentación positiva en el que la sobreexplotación de recursos genera impactos socio-ecológicos que se solucionan con más infraestructuras que alimentan el crecimiento y la demanda, generando a su vez nueva escasez (Molle 2006). Este círculo vicioso de la escasez artificial es lo que el gobierno andaluz llama "déficit estructural", algo que no se puede arreglar repitiendo las mismas acciones una y otra vez.

Me gustaría añadir una nota de cautela sobre la eficiencia como la nueva estrategia discursiva global para la gestión del agua. La eficiencia se define y calcula de diferentes maneras (eficiencia técnica, productiva, de asignación) y esto hay que hacerlo explícito. El aumento de la eficiencia técnica del riego o el abastecimiento (aumentando el ratio de uso neto respecto al bruto) requiere aumentar la complejidad infraestructural, reduciendo la capacidad adaptativa y la resiliencia. La eficiencia productiva es un sinónimo del aumento de la productividad o abastecer a más usuarios por unidad de recurso (menores ratios de uso per cápita o kilo). Si bien esto es generalmente celebrado como una forma de reducir el consumo de recursos, debería prestarse más atención a la compensación de ahorros con nuevas demandas. Los aumentos de productividad provocan una bajada de precios del recurso que a su vez atrae a nuevos inversores. Lo mismo ocurre con la eficiencia en la asignación que pide que los recursos se adjudiquen a las actividades económicamente más beneficiosas (más € por litro), lo que genera nuevas expectativas que alimentan la expansión de dichas actividades. Esto es lo que explica la famosa paradoja de Jevons: las mejoras en la eficiencia conducen a largo plazo al aumento del tamaño estructural del sistema y por lo tanto al incremento de la demanda total. Hasta el momento, esta paradoja no ha sido rebatida en gestión del agua aunque existe un intenso debate académico respecto a las condiciones para evitar el efecto rebote en el aumento de la eficiencia del regadío (Sampedro y del Moral 2014, Berbel et al. 2015). Además, los costes estructurales asociados al aumento de la eficiencia que no se consideran en la planificación. En definitiva, un claro reto actual

[49] Estoy terminando de escribir esta tesis justo el mismo día que los líderes del mundo se reúnen en la Conferencia de Desarrollo Sostenible de Naciones Unidas de 2015 para aprobar los nuevos Objetivos de Desarrollo Sostenible. Leyendo la propuesta que hay sobre la mesa, parece que los límites que he discutido son reforzados en la nueva agenda que guiará la acción de desarrollo global en los próximos quince años.

tanto de investigación como de gestión es el desarrollo de mecanismos de contabilidad, evaluación y rendición de cuentas para asegurar que la eficiencia, en cualquiera de sus formas, sea una estrategia eficaz para el propósito de controlar la demanda y no para contribuir al círculo vicioso de la escasez.

Una reflexión general final es que la visión dominante tecnocrática de la gestión del agua continúa buscando, o pretendiendo buscar, soluciones gana-gana-gana a problemas ambientales complejos. Puede que sea razonable empezar a reconocer que la mayoría de las veces éstas terminan siendo realidades gana-pierde-pierde (Scheidel 2013), ya sea entre dimensiones de la sostenibilidad, o entre los miembros de un mismo sistema hidrológico, o de diferentes sistemas. Evaluaciones críticas de los costes y resultados de estrategias políticas son fundamentales para aprender y mejorar la capacidad adaptativa. Es más, reclamaría un sabio reconocimiento político de la necesidad de abrir debates transdisciplinares sobre cuándo suficiente es suficiente (Molle 2006).

Para terminar esta sección, me gustaría proponer las principales lecciones de lo que, en mi opinión, funciona en cada región estudiada que podría contribuir a mejorar la gestión en la otra. Creo que la política de agua en Arizona puede aprender de la Directiva Marco Europea en lo que se refiere a objetivos políticos más ambiciosos, una mejor demarcación de las unidades de gestión incluyendo todo el territorio y una gestión ambientalmente más racional que podría ayudar a abordar retos emergentes sobre los ecosistemas dependientes del agua subterránea. Establecer los objetivos de gestión a la escala de masa de agua permite una mejor caracterización subregional de patrones socio-ecológicos y escapar del reduccionismo de la contabilidad de caja negra. En lo que respecta al Andarax, el principal aprendizaje es la drástica diferencia en la confianza hacia los gestores y tomadores de decisiones. Por mis observaciones allí, esta confianza se ha construido sobre un control y monitorización efectivos de las extracciones, una contabilidad real obligatoria como base para evaluar y planificar, una transparencia ejemplar de las agencias públicas, la existencia de mecanismos de rendición de cuenta para los tomadores de decisiones, y una participación pública mucho más efectiva. Finalmente, creo que ambas políticas de agua podrían beneficiarse de una visión socio-ecológica integrada que contribuiría a diagnosticar y resolver problemas de una forma más compleja y espero que útil.

Reflexiones sobre las experiencias inter y transdisciplinares de esta investigación

La interdisciplinariedad, en mi opinión, es un camino en curso que tardaremos muchos años en recorrer. A pesar de mis esfuerzos por integrar marcos y herramientas analíticas provenientes de distintas disciplinas científicas, es obvio que no soy experta en todas ellas, o incluso en ninguna de ellas. Teniendo una formación multi-disciplinar, me resulta relativamente sencillo entender diferentes narrativas científicas y sus construcciones sobre una misma realidad, y me encuentro cómoda navegándolas, traduciéndolas y encontrando relaciones entre ellas. Sin embargo, también pierdo rigor metodológico y entro en pantanosas áreas de eclecticismo. Mi objetivo es formar parte de equipos interdisciplinares en los que poder encontrar vías para el diálogo efectivo entre áreas de conocimiento y posiciones epistemológicas.

Mi experiencia dentro del grupo de estudiantes del proyecto SWAN me ha permitido aprender algunas lecciones para el futuro con respecto a los retos del trabajo interdisciplinar, que no están muy lejos de los que enfrentan cualquier grupo diverso de humanos que intentan trabajar de manera colaborativa. Antes de nada merece la pena enfatizar que trabajar en grupos interdisciplinares con un marco de análisis común, como el metabolismo social o los servicios ecosistémicos, es mucho menos complicado que si cada miembro del grupo aplica su propio marco. Esto se debe a que integrar metodologías es mucho más fácil que integrar construcciones mentales y epistemologías en el continuo realismo-constructivismo. Este segundo caso más complejo era precisamente el del grupo SWAN.

En este tipo de grupo interdisciplinar, el proceso de modelado conceptual, y por lo tanto sus resultados, obviamente seguirá diferentes caminos en función de cuáles son las disciplinas sentadas en la mesa y de quién lidere la discusión. Puesto que el peso del grupo estaba más en las aproximaciones cuantitativas, al principio nos encontramos más cómodos hablando de integración de variables y modelos que de poder o conflictos, los cuales tardaron más en ser entendidos. Puesto que los conceptos tenían significados diferentes para cada uno de nosotros, las discusiones sobre definiciones de consenso podían llevar horas, a veces sin demasiado éxito. Existe una inconmensurabilidad irreducible que tiene que ser asumida y, añadiría, abrazada de forma generosa. De hecho, los puntos de desacuerdo eran precisamente aquellos que empujaban las discusiones a llegar a mayor profundidad y creatividad.

Después de cuatro meses de reuniones, no habíamos sido capaces de elaborar un marco conceptual integrado, básicamente debido a estas diferencias epistemológicas irreductibles. Nuestra decisión entonces fue optar por un caso de estudio común en el que intentar generar una retroalimentación de lo abstracto a lo empírico y después retorno a lo abstracto. Los resultados de aquella decisión están aún por llegar cuando completemos el proceso en 2016, pero seguramente serán diferentes a lo que habíamos imaginado pues el grupo ha evolucionado. Los grupos de investigación cambian continuamente, con nuevas personas incorporándose y otras marchándose, y con ellas sus intereses y limitaciones personales. Establecer objetivos comunes que requieren pensamiento colectivo y colaboración a largo plazo puede resultar una tarea muy complicada.

La pregunta sobre cuál es nuestro papel como investigadores es una de las claves que subyacen a la dificultad en avanzar hacia colaboraciones transdisciplinares con actores fuera de la academia. El balance entre ser coherente con tus intereses individuales y hacer que tus resultados sean inteligibles, útiles y utilizados por grupos o actores sociales es delicado. Es más, existe una clara tensión entre trabajar de manera orientada a problemas y producir artículos científicos punteros en revistas de alto impacto porque el mundo académico está en su mayoría bastante desconectado de las necesidades sociales. Los procesos participativos son complejos, difíciles de organizar y muchas veces frustrantes. La facilitación es esencial para asegurar una participación equilibrada y lidiar con los temas micro-políticos. Además, hay que tener muy en cuenta cuestiones éticas en cuanto a participación de quién y con qué propósito, reconociendo que los participantes no son sujetos de estudio sino miembros activos del proceso científico. Me gustaría añadir una llamada a la humildad en el ámbito académico cuando trabajamos con personas que tienen sus necesidades, deseos y sueños, cuyo cumplimiento no es el objetivo de nuestra investigación. Tomarse estas cuestiones seriamente cuando diseñamos un proyecto de investigación requiere hacer trabajo previo a la obtención de fondos, lo es difícil sobre todo en grupos de investigación precarios.

En cuanto a mis experiencias transdiciplinares en los dos casos de estudio, en la cuenca de Tucson la interacción con actores fue mucho más fructífera que en el Andarax porque tenía un proyecto de investigación que me apoyaba desde el principio. Además, la cultura de diálogo y cooperación en Estados Unidos es mucho más intensa y está más extendida entre los gestores públicos, los cuales estuvieron muy abiertos a venir a reuniones, discutir nuestras preguntas y darme opiniones y sugerencias sobre mi trabajo allí. La pobre tradición deliberativa de España dificulta claramente una colaboración más provechosa entre investigadores y gestores. Por mi parte encontré grandes dificultades en traducir conceptos complejos a personas que trabajan fuera del ámbito académico y en intentar conectar el conocimiento teórico abstracto con el empírico de la resolución diaria de problemas. En ambos casos realicé ejercicios de cuantificación de indicadores y análisis multi-criterio de la sostenibilidad (Apéndice 3 y 5). Esto es algo que los gestores en las dos áreas encontraron útil para su trabajo. Sin embargo, los resultados de dichos ejercicios no fueron los esperados debido a la falta de recursos, de experiencia en facilitación o a limitaciones de tiempo. Por lo tanto, actividades que requirieron mucho trabajo no produjeron resultados académicos publicables, aunque sí me facilitaron una perspectiva mucho más profunda de la gestión del agua en ambas regiones.

En conclusión, a pesar de los múltiples retos y errores cometidos en mis intentos transdisciplinares durante el desarrollo de esta tesis, han sido experiencias de apertura mental extraordinarias que han reforzado aún más mi determinación en hacer del conocimiento científico algo útil para problemas reales. Mi impresión es que apenas he abierto pequeñas ventanas a un inmenso océano y que el largo viaje de navegación requerirá compromiso y financiación. Janice Dickinson del Laboratorio de Ornitología de Cornell nos preguntó en una conferencia de SWAN "¿Cómo pretendéis obtener un trabajo en el mercado académico si os convertís en investigadores sin especialidad?" Mi respuesta fue que valorar la experiencia inter y transdisciplinar puede que sea la única oportunidad que tenemos de resolver los problemas ambientales.

Ideas para futuras investigaciones

Investigación sobre el metabolismo hídrico de sistemas socio-ecológicos

El marco de análisis del metabolismo hídrico es bastante reciente y aún no ha sido suficientemente testado. El ser semánticamente abierto aporta flexibilidad y robustez a este marco, así como la capacidad de incorporar continuamente nuevos desarrollos, pero también requiere un esfuerzo para llegar a un grado mínimo de normalización metodológica. Para avanzar hacia esta estandarización son aún necesarios más casos de estudio coordinados.

Un camino abierto en esta tesis que requiere de mayor desarrollo es la integración de modelos eco-hidrológicos en el esquema de contabilidad de MuSIASEM de manera espacialmente explícita. BalanceMed permite separar el agua productiva del suelo de la no productiva (transpiración de evaporación) pero no modela de momento otros procesos importantes como la erosión o la contaminación del agua. Para estos propósitos existen otros modelos integrados como SWAT o WIMMed. Algunas cuestiones derivadas de la modelización en el capítulo 2 son la exploración del *efecto combinado sobre los fondos de agua y los ecosistemas acuáticos del cambio climático/períodos de sequía, el colapso de los usos del suelo tradicionales y la evolución de las coberturas vegetales, o los impactos sobre los acuíferos y sistemas dependientes del aumento de la eficiencia del regadío.* Estas preguntas se pueden analizar a través de la construcción de escenarios integrando predicción eco-hidrológica y la evaluación del nexo entre agua-energía-tierra-comida de MuSIASEM.

La integración del análisis espacial del metabolismo social y ecológico del agua requiere también una mayor exploración. El agua en Europa ofrece un ámbito particularmente apropiado para avanzar en análisis que usen los ecosistemas como criterio prioritario para establecer el nivel focal del sistema socio-ecológico debido a los sistemas de monitorización de la integridad de los ecosistemas acuáticos que se están desplegando para cada masa de agua. Desde una perspectiva de 'cuenca de problemas', el análisis a niveles eco-hidrológicos menores que la cuenca podría integrarse con el análisis de sistemas rurales que está bien desarrollado con MuSIASEM, permitiendo una evaluación bastante afinada de la deseabilidad, viabilidad y factibilidad de patrones metabólicos. La conexión de estos análisis metabólicos a resoluciones más finas con la gobernanza del agua tendría que abordar el reto de cómo ampliarlo hasta la cuenca. *¿Cuál es la escala más apropiada para la definición integrada de patrones socio-ecológicos de metabolismo hídrico? ¿Cómo caracterizar las relaciones espaciales entre estos patrones? ¿Cómo se pueden integrar el análisis espacial de sistemas rurales y del metabolismo hídrico? ¿Cómo escalar este análisis para generar información útil para la planificación hidrológica?*

Puesto que el WMSES es un marco teórico complejo, aún hace falta operacionalizar de manera apropiada algunos aspectos conceptuales. Uno de ellos es la definición impredicativa de recursos hídricos a través de la identificación de atributos relevantes y del rango útil de valores de dichos atributos. Puesto que los datos con los que he trabajado son normativos, asumí que esos flujos se proveen con una calidad deseable y el proceso seguido fue la desagregación de arriba a abajo de la demanda total de agua para los diferentes sectores. Sin embargo, sería interesante explorar otras formas de definición normativa de recursos hídricos útiles, por ejemplo a través de participación social *¿Cuáles son las características que hacen el agua útil de acuerdo con los usuarios? ¿Cuáles son la calidad, frecuencia y localización deseables para proveer diferentes tipos de servicios? ¿Cómo definir flujos de agua en función de estos atributos? ¿Cuáles son los flujos deseables que la gestión actual no provee?* Otra área conceptual interesante a explorar es el análisis de usos sociales no productivos de los fondos de agua, como se está haciendo en el análisis de servicios culturales de los ecosistemas. Esto permitiría por ejemplo avanzar a definiciones más complejas de productividad del agua incorporando valores estéticos que son clave en la actual evolución hacia el sector servicios en áreas rurales de alta montaña. *¿Cómo identificar, cualificar, y cuantificar los usos sociales de los fondos de agua? ¿Cuál es el valor de los fondos de agua? ¿Existen metodologías útiles para este propósito en el marco de los servicios ecosistémicos?*

Con respecto a la aplicación del marco del metabolismo hídrico a la evaluación de las estrategias de gestión del agua, creo que la estandarización de metodologías para evaluar cada tipología de estrategia (aumento del recurso, mejora de cada tipo de eficiencia, control del crecimiento, etc.) permitiría entender con más profundidad el efecto de cada una de ellas sobre los resultados observados. El análisis del Efecto-Sudoku en MuSIASEM puede ser muy útil para construir marcos de evaluación integrada de esta interacción que puedan ser adaptados a las especificidades de cada tipo de política y gestión regional, y aplicados tanto en el análisis previo de escenarios y costes para tomar decisiones, como con posterioridad para evaluar resultados *¿Cómo aplicar el Efecto-Sudoku para diseccionar los efectos de diferentes estrategias de gestión?* Esto requeriría resolver un problema anterior que es el de *cómo organizar la contabilidad del agua para permitir esta evaluación.*

Finalmente, creo que aún se necesita bastante trabajo de 'traducción' del marco del metabolismo hídrico para que sea útil en procesos participativos. La pesada carga conceptual requiere formas de comunicación efectivas y las herramientas de análisis integrado necesitan visualizaciones útiles accesibles para un público no académico *¿Cómo visualizar patrones metabólicos para facilitar discusiones transdisciplinares?* En este sentido creo que los visores SIG tienen muchas ventajas a la hora de facilitar un entendimiento común de los problemas ambientales y por ello tienen un futuro prometedor en los estudios de metabolismo.

Investigación sobre gobernanza del agua

En el marco del proyecto SWAN, el equipo de investigación de la Universidad de Sevilla desarrolló una línea de investigación sobre datos, información y conocimiento para la gobernanza del agua en la sociedad red que, en mi opinión, da en el clavo de algunos retos importantes del sector. Algunas preguntas de investigación abiertas son *¿Cuáles son las condiciones para que los mecanismos de participación y deliberación en la planificación hidrológica aseguren una participación y capacidad de decisión equilibrada? ¿Pueden las TICs jugar un papel más importante en mejorar la calidad democrática de la toma de decisiones en la gestión del agua?* En mi opinión, es necesario avanzar hacia sistemas de información del agua integrados, datos abiertos y plataformas de visualización y descarga. Como he discutido en esta disertación, la transparencia en la información del agua es un tema clave en España, pero también lo es en muchos otros países, debido sobre todo a las viejas inercias de ingenieros y gestores que consideran que la información del agua es demasiado compleja para ser entendida por no expertos. Esta era de 'guardianes de la verdad' se ha terminado, y las administraciones públicas poco a poco empiezan a moverse hacia estándares abiertos. Las organizaciones ciudadanas juegan un papel fundamental en controlar la calidad de la información que se utiliza para tomar decisiones y evaluar sus resultados. Mejorar la calidad y accesibilidad de los datos puede por tanto impulsar el progreso hacia la evaluación integrada de la gobernanza del agua.

Las prácticas emergentes de ciencia ciudadana son bastante prometedoras para empujar en esta dirección a través de la colaboración entre investigadores, gestores, usuarios y comunidades locales, activistas o el público en general. La inclusión efectiva de actores no académicos en el proceso de investigación está creando no sólo oportunidades de investigar a escalas antes imposibles, permitiendo la aplicación de técnicas de análisis big-data, sino también abriendo nuevas vías para el diálogo transdisciplinar y para el control externo del proceso científico *¿Cómo puede la ciencia ciudadana ayudar a suturar las brechas entre ciencia y gobernanza del agua?*

En cuanto al análisis de discurso, soy consciente de que la metodología utilizada en tesis no es la más rigurosa considerando los avances con softwares específicos como Atlas.ti o Envivo, y que se puede mejorar bastante en este sentido. Una línea de investigación que me gustaría explorar próximamente es el uso de las redes sociales en conflictos ambientales o campañas activistas relacionadas, combinando el análisis de redes con el del discurso. Para ello estoy colaborando en un artículo con el objetivo de responder a la pregunta *¿Qué tipo de capital social refuerzan las redes sociales?*

Por último, hay dos cajas negras importantes que no he abierto en esta tesis pero que espero poder abordar en el futuro: instituciones y poder. Aunque mencionadas y reconocidas como esenciales condicionantes de las relaciones socio-ecológicas, no he analizado en detalle las organizaciones institucionales específicas, ni tampoco las relaciones de poder entre actores, en parte porque carezco de formación para ello. Creo que un reto urgente no sólo para la gestión del agua sino para la mayoría de los ámbitos de la gestión pública es cómo escalar de manera efectiva la participación ciudadana desde lo local a escalas superiores. Puesto que la participación normalmente funciona bien en la escala comunitaria de gestión de recursos comunes, pero las TICs e internet han abierto nuevas oportunidades para una gestión y toma de decisiones democrática a todos los niveles, *¿Qué tipo de organización institucional puede hacer la participación de abajo-arriba eficaz y mejorar la legitimidad de las decisiones en gestión del agua? ¿Cómo se puede concebir un régimen institucional de gobernanza socio-ecológica multi-escalar y abierta? ¿Ayudaría este diseño a superar los regímenes post-políticos actuales o correría el riesgo de reforzarlos?*

REFERENCES

ADWR - Arizona Department of Water Resources. 2015a. Interview

ADWR - Arizona Department of Water Resources. 2015b. Long Term Storage Account (LTSA) Summary. Updated on February 23, 2015. [online] URL accessed February 2015: http://www.azwater.gov/azdwr/WaterManagement/Recharge/default.htm

ADWR - Arizona Department of Water Resources. 1999. Third Management Plan for the Tucson Active Management Area, 2000-2010. [online] URL accessed February 2015: http://www.azwater.gov

ADWR - Arizona Department of Water Resources. 2007. Annual status report: underground water storage, savings and replenishment (recharge) program. [online] URL accessed February 2015: http://www.azwater.gov/azdwr/WaterManagement/Recharge/default.htm

ADWR - Arizona Department of Water Resources. 2008. Regional recharge plan. Tucson Active Management Area Institutional and Policy Advisory Group. [online] URL accessed February 2015: http://www.azwater.gov/azdwr/WaterManagement/AMAs/TucsonAMA/documents/RRP_Ch1_and_Ack.pdf

ADWR - Arizona Department of Water Resources. 2010a. Draft Demand and Supply Assessment 1985-2010. Tucson Active Management Area. [online] URL accessed February 2015: http://www.azwater.gov/AzDWR/WaterManagement/Assessments/default.htm

ADWR - Arizona Department of Water Resources. 2010b Enhance aquifer management: alternative cut to the aquifer. [online] URL accessed February 2015: http://www.azwater.gov/azdwr/WaterManagement/AMAs/EnhancedAquiferManagementStakeholderGroup.htm

Aguilera Klink, F. 1995. El Agua como Activo Económico, Social y Ambiental. *El Campo*.

Akhter, M., Ormerod, K.J., and Scott, C.A. 2010. Lost in Translation: Resilience, Social Agency, and Water Planning in Tucson, Arizona. *Critical planning* 17:46-65.

Allan, J.A. 1998. Virtual Water: A Strategic Resource. Global Solutions to Regional Deficits. *Groundwater* 36(4): 545–546.

Allan, J.A. 1999. Productive efficiency and allocative efficiency: why better water management may not solve the problem. *Agricultural Water Management* 40(1):71–79.

Allan, J.A. 1999. Water in international systems: a risk society analysis of regional problemsheds and global hydrologies. In *Sustainablity, Risk and Nature: The Political Ecology of Water in Advanced Societies,* 73–82. European Science Foundation School of Geography, Oxford.

Allan, J.A. 2001. *The Middle East Water Question: Hydropoliticis and the Global Economy*. 1st edition. I.B. Tauris.

Allan, J.A. 2003. Virtual Water-the Water, Food, and Trade Nexus: Useful Concept or Misleading Metaphor? *Water International* 28(1):106–112.

Allan, J.A. 2006. IWRM: The New Sanctioned Discourse? In *Integrated Water Resources Management: Global Theory, Emerging Practice and Local Needs,* 404. Ajaya Dixit and Kusum Athukorala, New Deli.

Allen, T.F.H. 2008. Hierarchy Theory in Ecology. In Sven Erik Jørgensen and Brian D. Fath (Eds) *Encyclopedia of Ecology,* 1852–1857. Academic Press, Oxford.

Allen, T.F.H., and Giampietro, M. 2006. Narratives and transdisciplines for a post-industrial world. Syst. Res. *Behavioral Sciences* 23:595–615.

Allen, T.F.H., and Giampietro, M. 2014. Holons, creaons, genons, environs, in hierarchy theory: Where we have gone. *Ecological Modelling* 293(10): 31–41.

Allen, T.F.H., and Hoekstra, T.W. 1992. *Towards a unified ecology*. Columbia University Press, New York.

Allen T.F.H., and Starr T.B. 1988. *Hierarchy: Perspectives for Ecological Complexity*. University of Chicago Press, Chicago.

Andreo, B., Vías, J., López-Jeta, J.A., Carrasco, F., Durán, J.J., and Jiménez, P. 2004. Propuesta metodológica para la estimación de la recarga de acuíferos carbonáticos. *Boletín Geológico Minero* 115:177–186.

Aspinall, R.J. 2014. Land systems: Multi-scale dynamics of human and environmental systems. In Giampietro et al. (Eds), *Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Use,* 49–57. Routledge Explorations in Sustainability and Governance. Routledge, New York.

Aspinall, R.J., and Serrano-Tovar, T. 2014. GIS protocols for use within MuSIASEM. In Giampietro et al. (Eds), *Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Use,* 135–146. Routledge Explorations in Sustainability and Governance. Routledge, New York.

AWBA - Arizona Water Banking Authority. 2012. Annual plan of operation. [online] URL accessed February 2015: http://www.azwaterbank.gov/Plans_and_Reports_Documents/Annual_Plan_of_Operation.htm

AWBA - Arizona Water Banking Authority. 2014. Recovery of water stored by the AWBA. A Join plan of AWBA, ADWR and CAP. Draft. [online] URL accessed February 2015: http://www.azwaterbank.gov/Plans_and_Reports_Documents/Annual_Plan_of_Operation.htm

Aylward, B., Bandyopadhyay, J., Belausteguigotia, J.C. and Borkey, P. 2005. Freshwater Ecosystem Services. In K. Chopra et al. (Eds.), *Ecosystems and Human well-being: Policy Responses*. INLAND PRESS, Washington, 3:213–255.

Ballester, A., and Parés, M. 2013. Democracia deliberativa y política de agua: Experiencias de participación en el contexto de la Directiva Marco del Agua en España. In *Proceedings of the VIII Iberian Congress of Water Management and Planning,* 178–190. Lisbon, Portugal.

Ballester, A., and Espluga, J. 2012. Análisis de Las Entrevistas Realizadas En Relación Con El Proceso de Participación Asociado a La Elaboración Del Plan Hidrológico de La Demarcación de La Cuencas Mediterráneas Andaluzas. PART-DMA project. Unpublished report. Autonomous

University of Barcelona. [online] URL accessed August 2015: http://blogs.uab.cat/partdma/documentacion/.

Barbas Baptista, G. 2010. Bridging environmental conflicts with social metabolism forestry expansion and socioeconomic change. PhD Thesis Environmental Sciences. [online] URL accessed November 2011: http://phd.gualter.net/.

Barry, J.T. M.A. 2011. WHO SAID WHAT? A Report on Public Comments Submitted to the Joint Water and Wastewater Infrastructure, Supply & Planning Study, A City of Tucson and Pima County Cooperative Project. Executive Summary. [online] URL accessed February 2015: http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=135647

Bartolini, F. Bazzani, G., Gallerani, V., Raggi, M., and Viaggi, D. 2007. The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models. *Agricultural Systems* 93(1-3):90-114.

Bateson, G. 2000. *Steps to an ecology of mind*. University of Chicago Press, Chicago.

Bautista, E., Waller, P., and Roanhorse, A. 2010. *Evaluation of the Best Management Practices Agricultural Water Conservation Program*. Phoenix, AZ: Arizona Department of Water Resources. [online] URL accessed September 2015: http://www.azwater.gov/azdwr/WaterManagement/AMAs/PinalAMA/documents/EvaloftheBMPReport.pdf

Beck, U. 1998. *World Risk Society*. Polity Press, Cambridge.

Becker, E. 2012. Social-Ecological Systems as Epistemic Objects. Working paper from the Institute for Social-Ecological Research (ISOE), Frankfurt/Main. [online] URL accessed August 2015: http://www.isoe.de/ftp/publikationen/eb_socecsystem2010.pdf

Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J.A., Camacho, E., and Montesinos, P. 2015. Literature Review on Rebound Effect of Water Saving Measures and Analysis of a Spanish Case Study. *Water Resources Management* 29(3):663–78.

Berkes, F., Colding, J., and Folke, C. 2003. Introduction. In *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change,* 1–30. Cambridge University Press, New York.

Berkes, F., and Folke, C. 1998. *Linking sociological and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, New York.

Binder, C.R., Hinkel J., Bots P.W.G., and Pahl-Wostl, C. 2013. Comparison of Frameworks for Analyzing Social-Ecological Systems. *Ecology and Society* 18(4):26.

Boström, M. 2012. A missing pillar? Challenges in theorizing and practicing social sustainability: introduction to the special issue. *Sustainability Science, Practice and Policy* 8(1):3–14.

Bouleau, G., and Pont, D. 2015. "Did You Say Reference Conditions? Ecological and Socio-Economic Perspectives on the European Water Framework Directive." *Environmental Science and Policy* 47 (March):32–41.

Braden, J.B., Brown, D.G., Dozier, J., Gober, P., Hughes, S.M., Maidment, D.R., Schneider, S.L., Schultz, P.W., Shortle, J.S., Swallow, S.K., and Werner, C.M. 2009. Social science in a water observing system. *Water Resources Research* 45(11):W11301.

Brauman, K.A., Daily G. C., Duarte T.K., and Mooney, H.A. 2007. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annual Review of Environment and Resources* 32(1):67–98.

Bredehoeft, J. 1997. Safe Yield and the Water Budget Myth. *Ground Water* 35(6): 929–929.

Brooks, C. 2103. *ADWR Enhanced Aquifer Management Proposal* – Evaluation comment. [online] URL accessed February 2015: http://www.azwater.gov/azdwr/WaterManagement/AMAs/EnhancedAquiferManagementStakeholderGroup.htm

Brooks, D.R., Collier, J., Maurer, B.A., Smith, J.D.H., and Wiley, E.O. 1989. Entropy and information in evolving biological systems. *Biology and Philosophy* 4(4):407–432.

Buhangin, J. 2013. Spatial Equity: A Parameter For Sustainable Development In Indigenous Regions. WIT Press, Southampton.

Bukowski, J. 2007. Spanish Water Policy and the National Hydrological Plan: An Advocacy Coalition Approach to Policy Change. *South European Society and Politics* 12(1):39–57.

Buttel, F.H., Hawkins, A.P., and Power, A.G. 1990. From limits to growth to global change: Constraints and contradictions in the evolution of environmental science and ideology. Global Environmental Change 1:57–66.

Cabello, V., and Madrid, C. 2014. Water use in arid rural systems and the integration of water and agricultural policies in Europe: the case of Andarax river basin. *Environment, Development and Sustainability* 16(4):957–975.

Cabello, V., Willaarts, B., Aguilar, M., and del Moral, L. 2015. River basins as socio-ecological systems: linking levels of societal and ecosystem metabolism in a Mediterranean watershed. *Ecology and Society* 20(3):20.

Cadillo-Benalcazar, J., Giampietro, M., Serrano-Tovar, T., and Bukkens, S.G.F. 2014. Food grammar. In Giampietro et al. (Eds), *Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Use,* 73–89 Routledge Explorations in Sustainability and Governance. Routledge, New York.

CAGRD – Central Arizona Groundwater Replenishment District. 2014. Plan of Operation 2015. Draft. [online] URL accessed February 2015: http://www.cagrd.com/index.php/operations/plan-of-operation

CAP – Central Arizona Project. 2009. The Navajo Generation Station Whitepaper. Quoted in: Background on Navajo Generating Station Impacts to Arizona in Anticipation of Proposed EPA Coal Plant Emissions. [online] URL accessed August 2015: https://energypolicy.asu.edu/wp-content/uploads/2012/03/NGS-brief-sheet.pdf

CAP – Central Arizona Project. 2015. Accounting of deliveries and LTSCs from Central Arizona Water Conservation District sites. [online] URL accessed February 2015: http://www.cap-az.com/departments/recharge-program

Caparros, R. 2010. Paisaje Agricola. In Martinez, M. and Usero, S. (Eds.) *Río Andarax*, 127-133. Agencia Andaluza del Agua, Sevilla.

Chemero, A., and Turvey, M.T. 2008. Autonomy and hypersets. *Biosystems* 91(2): 320–330.

Clark, W.C. 2007. Sustainability Science: A room of its own. *Proceedings of the National Academy of Sciences* 104(6):1737–1738.

Cohen, A., and Davison, S. 2011. An examination of the watershed approach: Challenges, antecedents, and the transition from technical tool to governance unit. *Water Alternatives* 4(1):1–14.

Commoner, B. 1971. *The Closing Circle: Nature, Man, and Technology*. Random House Inc, New York.

Connolly, T.M., and Begg, C.E. 2009. *Database Systems: A Practical Approach to Design, Implementation and Management*, 5th edition. Addison Wesley, Boston and London.

Contreras, S., Boer, M.M., Alcala, F.J., Domingo, F., Garcia, M., Pulido-Bosch, A., and Puigdefabregas, J. 2008. An ecohydrological modelling approach for assessing long-term recharge rates in semiarid karstic landscapes. *Journal of Hydrology* 351(1-2):42– 57.

Corominas, J. 2010. Agua y energía en el riego en la época de la sostenibilidad. *Ingeniería del Agua* 17(3).

Cory, D.C., Evans, M.E., Leones, J.P., and Wade, J.C. 1992. The Role of Agricultural Groundwater Conservation in Achieving Zero Overdraft in Arizona. *Water Resources Bulletin* 28(5):889-901.

Cottrell, W.F. 1955. *Energy and Society: The Relation Between Energy, Social Change, and Economic Development*. McGraw-Hill.

Cullom, C. 2014. *Colorado River update: risks and vulnerabilities.* Presentation in Sustainable Water Action project visit to CAP facilities.

Curran, M.A. 2009. Wrapping Our Brains around Sustainability. Sustainability 1, 5–13.

D'Odorico, P., Laio, F., Porporato, A., Ridolfi, L., Rinaldo, A., and Rodriguez-Iturbe, I. 2012. Ecohydrology of Terrestrial Ecosystems. *Bioscience* 60(11):898–907.

Daly, H.E. 1973. *Toward a Steady-state Economy*. W.H.Freeman & Co Ltd, San Francisco.

De Aranzabal, I., Schmitz, M., Aguilera, P., and Pineda, F. 2008. Modelling of landscape changes derived from the dynamics of socio-ecological systems. A case of study in a semiarid Mediterranean landscape. *Ecological Indicators* 8(5):672-685.

de Groot, R.S., Wilson, M.A., and Boumans, R.M.J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41(3):393–408.

de Stefano, L., Fornés, J.M., López-Geta, J.A., and Villarroya, F. 2014. Groundwater use in Spain: an overview in light of the EU Water Framework Directive. *International Journal of Water Resources Development* 0(0):1–17.

del Moral, L. 2005. *La gestión del agua en Andalucía: aspectos económicos, políticosy territoriales*. Colección Andalucía XXI. Serie Economía. Mergablum, Sevilla.

del Moral, L. 2006. La Directiva Marco del Agua y la nueva política agraria. In *XII Informe socioeconómico de la Agricultura en España*, 44–51. Fundación de Estudios Rurales, Madrid.

del Moral, L., and Do O, A. 2014. Water governance and scalar politics across multiple-boundary river basins: states, catchments and territorial powers in the Iberian Peninsula. *Water International* 39(3):333–347.

del Moral, L., Pita, M.F., Pedregal, B., Hernandez-Mora, N., and Limones, N. 2014. Current paradigms in the management of water: Resulting information needs. *Publicationes Instituti Geographici Universitatis Tartuensis* 110: 21–31.

del Moral, L., Ferrer, G., Espín, E., and Fernández, M. 2007. Análisis de Los Discursos Relacionados Con Los Procesos Territoriales Que Condicionan La Presión Sobre El Agua En La Cuenca Del Segura. Unpublished report. *Spanish Geographers Association*.

del Moral, L., and Sauri D. 1999. Changing Course. Water Policy in Spain. *Environment* 41(6):12–36.

Devlin, J.F., and Sophocleous, M. 2005. The Persistence of the Water Budget Myth and Its Relationship to Sustainability. *Hydrogeology Journal* 14(1-2):267–267.

Diaz-Maurin, F., and Kovacic, Z. 2015. The unresolved controversy over nuclear power: A new approach from complexity theory. *Global Environmental Change* 31:207–216.

Dumont, A., Mayor, B., and López-Gunn, E. 2013. Is the Rebound Effect or Jevons Paradox a Useful Concept for better Management of Water Resources? Insights from the Irrigation Modernisation Process in Spain. *Aquatic Procedia*, At the Confluence - Selection from the 2012 World Water Week in Stockholm 1:64–76.

Eden, S., Scott, C.A., Lamberton, M.L., Megdal, S.B. 2011. *Water-energy interdependencies and the Central Arizona project*. In Kenney D. S. and Wilkinson R. (Eds) *The water-energy nexus in the American west*, 109-122. Edward Elgar Publishing Inc., Williston.

Ehrenfeld, J.R. 2012. Sustainability needs to be attained, not managed. *Sustainability Science, Practice and Policy* 4(2): 1–3.

Ewert, F., van Ittersum, M.K., Heckelei, T., Therond, O., Bezlepkina, I., and Andersen, E. 2011. Scale changes and model linking methods for integrated assessment of agri-environmental systems. *Agricultural Ecosystems and Environment* 142(1-2): 6–17.

Faber, M. 2008. How to be an ecological economist. *Ecological Economics,* Special Section: Integrated Hydro-Economic Modelling for Effective and Sustainable Water Management 66(1):1–7.

Faggi, P. 1996. Water in developing countries: productive and strategic values. In *Proceedings of the European Seminar on Water Geography: Perceptions of the Values of Water and Water Environments*, 113–116. SOAS, University of London, London.

Falkenmark, M. 1995. Land and water integration and river basin management. In *Proceedings of an FAO informal workshop*. Rome.

Falkenmark, M., and Rockström, J. 2004. *Balancing Water for Humans and Nature: The New Approach in Ecohydrology*. Routledge, London.

Farhad, S. 2012. Los sistemas socio-ecológicos: una aproximación conceptual y metodológica. In *Proceedings of the XIII Jornadas de Economía Crítica: Los costes de la crisis y alternativas en construcción,* 265-280. Sevilla, Spain.

Feitelson, E. 1996. The implications of changes in perceptions of water in Israel for peace negotiation with Jordan and the Palestinians. In *Perceptions of the Values of Water and Water Environments. Proceedings of the European Seminar on Water Geography*. SOAS, University of London, London.

Filardi, C.A. 2015. *Place in the World – Science, Society, and Reframing the Questions* We Ask. 1st International Conference on Citizen Science. Opening plenary. San Jose, California. [online] URL accessed March 2015: http://citizenscienceassociation.org/2014/11/07/keynote-speaker-announced-for-citizen-science-2015/

Fischer-Kowalski, M., 1998. Society′s Metabolism. The Intellectual History of Materials Flow Analysis, Part I, 1860– 1970. *Journal of Industrial Ecology* 2(1):61–78.

Fleck, B.E. 2013. *Factors affecting agricultural water use and sourcing in irrigation districts of central Arizona*. Msc thesis submitted to the faculty of the Department of Agricultural and Resource Economics. [online] URL accessed October 2015: http://gradworks.umi.com/15/44/1544387.html

Forstater, M. 2004. Visions and scenarios: Heilbroner's worldly philosophy, Lowe's political economics, and the methodology of ecological economics. *Ecological Economics* 51(1-2):17–30.

Frisvold, G.B., Wilson, P.N., and Needham, R. 2007. Implications of Federal Farm Policy and State Regulation on Agricultural Water Use. In Colby, B.G. & Jacobs K.L. (Eds), *Arizona Water Policy: Management Innovations in an Arid, Urbanizing Region,* 137-156. Resources for the Future, Washington D.C.

Funtowicz, S.O., and O′Connor, M. 1999. The passage from entropy to thermodynamic indeterminacy: a social and science epistemology for sustainability. In *Bioeconomics and Sustainability: Essays in Honor of Nicholas Georgescu-Roegen* Edward Elgar Publishing, Cheltenham, UK.

Funtowicz, S.O., and Ravetz, J.R. 1990. *Uncertainty and Quality in Science for Policy*. Springer Netherlands, Dordrecht.

Funtowicz, S.O., and Ravetz, J.R. 1993. Science for the post-normal age. *Futures* 25(7):739–755.

Gastelum, J.R. 2012. Analysis of Arizona's Water Resources System. *International Journal of Water Resources Development*, 28(4):615-628.

Georgescu-Roegen, N. 1971. *The Entropy Law and the Economic Process.* Harvard University Press, Cambridge.

Giampietro, M. 1994. Using hierarchy theory to explore the concept of sustainable development. *Futures*, Special Issue Complexity: Fad or Future? 26(6):616–625.

Giampietro, M. 2003. *Multi-Scale Integrated Analysis of Agroecosystems*. CRC Press LLC, Boca Raton, Florida.

Giampietro, M., Allen, T.F.H., and Mayumi, K. 2006a. The epistemological predicament associated with purposive quantitative analysis. *Ecological Complexity*. 3:307–327.

Giampietro, M., Aspinall, R.J., Ramos-Martin, J., and Bukkens, S.G.F. 2014. *Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Use*. Routledge Explorations in Sustainability and Governance. Routledge, New York.

Giampietro, M., and Bukkens, S.G.F. 2014. The multi-scale integrated analysis of societal and ecosystem metabolism. In Giampietro et al. (Eds) *Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Use*, 11–21. Routledge Explorations in Sustainability and Governance. Routledge, New York.

Giampietro, M., and Bukkens, S.G.F. 2015. Analogy between Sudoku and the multi-scale integrated analysis of societal metabolism. *Ecological Informatics*. Ecosystem Metabolism towards Sustainable Society Design and Management 26(Part 1):18–28.

Giampietro, M., and Lomas, P. 2014. The interface between societal and ecosystem metabolism. In Giampietro et al. (Eds.) *Resource Accounting for Sustainability: The Nexus between Energy, Food, Water and Land Use*, 33–48. Routledge Explorations in Sustainability and Governance. Routledge, New York.

Giampietro, M., and Mayumi, K. 2003. Impredicative Loop Analysis: dealing with the Representation of Chicken–Egg Processes. In Giampietro (Ed), *Multi-Scale Integrated Analysis of Agroecosystems*. CRC Press LLC, Boca Raton, Florida.

Giampietro M. and Mayumi K. 2008. The Jevons Paradox: The Evolution of Complex Adaptive Systems and the challenge for Scientific Analysis. In Polimeni, J.M., Mayumi, K., Giampietro, M. and Alcott, B. (Eds.) *The Jevons Paradox and the Myth of Resource Efficiency Improvements*, 79-140. Earthscan Research Edition, London.

Giampietro, M., Mayumi, K., and Munda, G. 2006b. Integrated assessment and energy analysis: Quality assurance in multi-criteria analysis of sustainability. *Energy* 31(1):59–86.

Giampietro, M., Mayumi, K. and Sorman, A.H. 2011. *The metabolic pattern of societies: where economists fall short.* Routledge, New York.

Giampietro, M., Mayumi, K., and Sorman, A.H. 2012. *Energy Analysis for a Sustainable Future: Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism*, 1st edition. Routledge.

Giampietro, M., Mayumi, K., and Ramos-Martin, J. 2009. Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. *Energy* 34(3):313–322.

Giampietro, M., and Sorman, A.H. 2009. Interlinkages and Forecasting made possible by the use of the DECOIN analytical tool kit (Deliverable 3.4 EU research project DECOIN No. 044428 FP6-2005-SSP-5A), ICTA Technical Report. Institute of Environmental Sciences and Technology, Barcelona.

Gill, T. 2011. New thinking on global water security: towards an ecohydrological perspective.

Gomiero, T., and Giampietro M. 2005. Graphic tools for data representation in integrated analysis of farming systems. *International Journal of Global Environmental Issues* 5(3/4):264–301.

Gomiero, T. 2004. Multi-Objective Integrated Representation (MOIR): an innovative tool for farming systems analysis. PhD thesis. Universitat Autònoma de Barcelona, Barcelona.

Guan, W., and Moore, L. 1996. Development of a GIS database for lake ecosystem studies. Proceedings of AWRA Symposium on GIS and water resources. Sept 22-26, 1996. Ft. Lauderdale, Florida. [online] URL Accessed October 2015: http://awra.org/~awra/proceedings/gis32/guan/

Gupta, J., and Pahl-Wostl, C. 2013. Global Water Governance in the Context of Global and Multilevel Governance: Its Need, Form, and Challenges. *Ecology and Society* 18(4): 54.

Haas, P.M. 1992. Introduction: Epistemic Communities and International Policy Coordination. *International Organization* 46(1):1–35.

Hajer, M., and Versteeg, W. 2005. A decade of discourse analysis of environmental politics: Achievements, challenges, perspectives. *Journal of Environmental Policy and Planning* 7(3):175–184.

Hajer, M.A. 1995. The politics of environmental discourse: ecological modernization and the policy process. Clarendon Press/Oxford University Press, Oxford, New York.

Hardy, L., and Garrido, A. 2010. Análisis y evaluación de las relaciones entre el agua y la energía en España. *Papeles de Agua Virtual,* 6. Observatorio del Agua. Fundación Marcelino Botin.

Hecht, A.D., Fiksel, J., Fulton, S., Yosie, T., Hawkins, N., Leuenberger, H., Golden, J.S., and Lovejoy, T.E. 2012. Creating the future we want. *Sustainability Science, Practice and Policy* 8(2):62–75.

Henriques, C., Holman, I.P., Audsley, E., and K. Pearn. 2008. An interactive multi-scale integrated assessment of future regional water availability for agricultural irrigation in East Anglia and North West England. *Climate Change* 90(1-2):89–111.

Hernandez-Mora, N. and De Stefano, L. 2012. Water planning and management after the EU Water Framework Directive. In De-Stefano and Llamas (Eds.) *Water, Agriculture and the Environment in Spain: Can we square the circle?*, 35-44. CRC Press/Balkema, Leiden.

Hernandez-Mora, N., Cabello, V., de Stefano, L., and del Moral, L. 2015. Networked water citizen organisations in Spain: Potential for Transformation of Existing Power Structures in Water Management. *Water Alternatives* 8(2): 99–124.

Hernández-Mora, N., del Moral, L., La-Roca, F., La Calle, A., and Schmidt, G. 2014. Interbasin Water Transfers in Spain: Interregional Conflicts and Governance Responses. In Graciela Schneier-Madanes (Ed.) *Globalized Water,* 175–94. Springer, Netherlands.

Hirt, P., Gustafson, A., and Larson, K. 2008. The mirage in the Valley of the Sun. *Environmental History* 13(3):482-514.

Hoekstra, A.Y., and Chapagain, A.K. 2006. Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resources Management* 21(1):35–48.

Hoekstra, A.Y., Mekonnen, M.M., Chapagain, A.K., Mathews, R.E., and Richter, B.D. 2012. Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability. *PLoS ONE* 7(2):e32688.

Holland, J. 1996. *Hidden Order: How Adaptation Builds Complexity*. Basic Books, Cambridge.

Holling, C.S. 2001. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* 4(2):390–405.

Hutchinson, C.F., Varady, R.G., and Drake, S. 2010. Old and New: Changing Paradigms in Arid Lands Water Management. In Schneier-Madanes, G., Courel, M.F. (Eds.), *Water and Sustainability in Arid Regions*, 311–332. Springer, Netherlands.

INE - Instituto Nacional de Estadística. 2011. *National population and housing census*. Instituto Nacional de Estadística, Madrid, Spain. [online] accessed August 2015: http://www.ine.es/censos2011_datos/cen11_datos_inicio.htm

IPAG - Tucson AMA Institutional and Policy Advisory Group. 1998. Regional recharge plan. [online] URL accessed February 2015: http://www.azwater.gov/azdwr/WaterManagement/Recharge/default.htm

Jacobs, K. 2009. *Groundwater management issues and innovations in Arizona.* Unpublished work. [online] URL accessed February 2015: http://admin.cita-aragon.es/pub/documentos/documentos_JACOBS_2-4_26d10f50.pdf

Jacobs, K., and Holway, J. 2004. Managing for sustainability in arid climates: Lessons learned from 20 years of groundwater management in Arizona, USA. *Hydrogeology Journal* 12(1):52-65.

Jakeman, A.J., and Letcher, R.A. 2003. Integrated assessment and modelling: features, principles and examples for catchment management. *Environmental Modelling & Software* 18(6):491–501.

Janssen, M.A., Bodin, J. M. Anderies, T. Elmqvist, H.Ernstson, R.R. J. McAllister, P. Olsson, and P. Ryan. 2006. Toward a Network Perspective of the Study of Resilience in Social-Ecological Systems. *Ecology and Society* 11(1):15.

Jarvis, R.M., Borrelle, S.B., Breen, B.B., and Towns, D.R. 2015. Conservation, mismatch and the research–implementation gap. *Pacific Conservation Biology* 21:105.

Jasanoff, S. 2005. *Designs on Nature. Science and democracy in Europe and the United States*. Priceton University Press, Priceton.

Jørgensen, S.E., and Nielsen, S.N. 2013. The properties of the ecological hierarchy and their application as ecological indicators. *Ecological Indicators* 28:48–53.

Kaika, M. 2003. The Water Framework Directive: A New Directive for a Changing Social, Political and Economic European Framework. *European Planning Studies* 11(3).

Kampas, A., Petsakos, A., and Rozakis, S. 2012. Price induced irrigation water saving: Unraveling conflicts and synergies between European agricultural and water policies for a Greek Water District. *Agricultural Systems* 113:28–38.

Kampis, G. 1991. *Self-modifying systems in biology and cognitive science: a new framework for dynamics, information, and complexity*. Pergamon Press.

Kates, R.W. 2001. Environment and Development: Sustainability Science. *Science* 292(5517):641–642.

Kemp, R., and Martens, P. 2007. Sustainable development: how to manage something that is subjective and never can be achieved? *Sustainability Science, Practice and Policy* 3(2):5–14.

Khun, T.S. 1962. The Structure of Scientific Revolutions. The University of Chicago, Chicago.

Kiser M., Megdal S., Stratton M., Vasquez V., and Zucker C. 2010. Report of the Regional Water Assessment Task Force "ThinkTank" Process. [online] URL accessed February 2015: https://www.pagnet.org/Default.aspx?tabid=185.

Klauer, B., Manstetten, R., Petersen, T., and Schiller, J. 2013. The art of long-term thinking: A bridge between sustainability science and politics. *Ecological Economics* 93:79–84.

Knight, F.H. 1964. *Risk, Uncertainty, and Profit*. A. M. Kelley, New York.

Koestler, A. 1970. Beyond Atomism and Holism—the Concept of the Holon. *Perspectives in Biology and Medicine* 13(2): 131–154.

Kovacic, Z., and Giampietro, M. 2015. Beyond "beyond GDP indicators:" The need for reflexivity in science for governance. *Ecological Complexity* 21:53–61.

Kunzmann, K.R. 1998. Planning for spatial equity in Europe. *International Planning Studies* 3(1):101-120.

La Calle, A. 2008. La Adaptación Española de La Directiva Marco Del Agua. In del Moral and Hernandez-Mora (Eds) *Panel Científico-Técnico de Seguimiento de La Política de Aguas*. Fundación Nueva Cultura del Agua.

Latorre, J.G., García-Latorre, J. and Sanchez-Picón, A. 2001. Dealing with aridity: socio-economic structures and environmental changes in an arid Mediterranean region. *Land Use Policy* 18(1):53–64.

Leach, M., Scoones, I., and Stirling, A. (Eds.) 2010. *Dynamic Sustainabilities: Technology, Environment, Social Justice*. Earthscan,London.

Letcher, R.A., Croke, B.F.W., and Jakeman, A.J. 2007. Integrated assessment modelling for water resource allocation and management: A generalised conceptual framework. *Environmental Modelling & Software* 22(5):733–742.

Li, N., and Ren, L. 2010. Application and assessment of a multiscale data integration method to saturated hydraulic conductivity in soil. *Water Resources Research* 46(9):W09510.

Liebig, J.F. von, Gregory, W., and Webster, J.W. 1843. Animal Chemistry: Or Organic Chemistry. In *Its Application to Physiology and Pathology*. J. Owen.

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H., and Taylor, W.W. 2007. Complexity of coupled human and natural systems. *Science* 317(5844):1513–1516.

Liu, Y., and Gupta, H.V. 2007. Uncertainty in hydrologic modeling: Toward an integrated data assimilation framework. *Water Resources Research* 43(7):W07401.

Liu, Y., Gupta, H., Springer, E., and Wagener, T. 2008. Linking science with environmental decision making: Experiences from an integrated modeling approach to supporting sustainable water resources management. *Environmental Modelling & Software* 23:846–858.

Lopez-Gunn, E., Rica, M., and Van Cauwenbergh, N. 2012a. Taming the groundwater chaos. In De-Stefano and Llamas (Eds.) *Water, Agriculture and the Environment in Spain: Can we square the circle?,* 227-239. CRC Press/Balkema, Leiden.

Lopez-Gunn, E., Mayor, B., and Dumont, A. 2012b. Implications of the modernization of irrigation systems. In De-Stefano and Llamas (Eds.) *Water, Agriculture and the Environment in Spain: Can we square the circle?*, 241-253. CRC Press/Balkema, Leiden.

Lotka, A. J. 1922. Contribution to the energetics of evolution. *Proceedings of the National Academy of Sciences* 8:147-151.

Lotka, A.J. 1956. *Elements of Mathematical Biology*. Dover Publications, New York.

Loris, A. 2008. The limits of integrated water resources management: a case study of Brazil's Paraíba do Sul River Basin. Sustain. *Sustainability Science, Practice and Policy* 4(2):4–11.

Losch, B. 2004. Debating the Multifunctionality of Agriculture: From Trade Negotiations to Development Policies by the South. *Journal of Agrarian Change* 4(3):336–360.

Luhmann, N. 1990. *Essays on Self-reference*. Columbia University Press.

MacLachlan, S.P., and Moulton, J.D. 2006. Multilevel upscaling through variational coarsening: Multilevel variational upscaling. *Water Resources Research* 42(2):W02418.

Madrid, J. 2006. Discursos y políticas sobre el agua y la agricultura. XII Informe socioeconómico de la Agricultura en España, 53-61. Madrid: Fundación de Estudios Rurales.

Madrid, C. 2014. *The water metabolism of socio-ecosystems. Epistemology, methods and applications*. PhD Thesis. Ph.D. Program in Environmental Science and Technology. Universitat Autònoma de Barcelona.

Madrid, C., and Cabello, V. 2011. Re-opening the black box in societal metabolism: the application of MuSIASEM to water. Working Paper. Institut de Ciència i Tecnologia Ambientals; Universitat Autònoma de Barcelona. [online] URL accessed October 2015: http://www.recercat.cat//handle/2072/172087.

Madrid, C., Cabello, V., and Giampietro, M. 2013. Water-Use Sustainability in Socioecological Systems: A Multiscale Integrated Approach. *BioScience* 63 (1):14-24.

Madrid, C., and Giampietro, M. 2014. The Water Grammar. In Giampietro et al (Eds.) *Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Use*. Routledge Explorations in Sustainability and Governance. Routledge, New York.

Madrid, C., and Giampietro, M. 2015. The water metabolism of socio-ecological systems: Reflections and a conceptual framework. *Journal of Industrial Ecology* (In press).

Maimone, M. 2004. Defining and Managing Sustainable Yield. *Ground Water* 42(6): 809–814.

Mancilla-García, M. 2015. Does Social Media Benefit Dominant or Alternative Water Discourses? *Water Alternatives* 8(2):125–146.

March, H., Therond, O., and Leenhardt, D. 2012. Water futures: Reviewing water-scenario analyses through an original interpretative framework. *Ecological Economics* 82:126-137.

March, H., Saurí, D. and Rico-Amorós, A.M. 2014. The End of Scarcity? Water Desalination as the New Cornucopia for Mediterranean Spain. *Journal of Hydrology*, Water governance across competing scales: Coupling land and water management Incorporating water resources in integrated urban and regional planning, 519, Part C (November): 2642–51.

Margalef, R. 1968. *Perspectives in ecological theory*. University of Chicago Press.

Martens, P. 2006. Sustainability: science or fiction? *Sustainability Science, Practice and Policy* 2(1):36–41.

Martínez, J. 2011. Estudio de la Huella Energética del abastecimiento urbano de la provincia de Almería. *Universidad de Almería*. [online] URL accessed October 2015: http://repositorio.ual.es:8080/jspui/bitstream/10835/1152/1/Estudio%20de%20la%20Huella%20Energetica%20del%20Abastecimiento%20Urbano%20de%20Agua%20de%20la%20Provincia%20de%20Almeria_Martinez%20Rodriguez,%20Francisco%20Javier.pdf

Martínez, J. 2015. La necesaria inflexión en la gestión de los recursos hídricos del Campo de Tabernas. *El AFA revista cultural* 32: 31–37.

Martínez, J.D. S., Jiménez, E.A., Guerrero, J.M., and Almonacid, A.G. 2008. La repoblación forestal de Sierra Morena, Jaén (1940-1984). *Anales de Geografía de la Universidad Complutense* 28(1):105–131.

Martínez, M., and Usero, S. (Eds.) 2010. *Río Andarax. Agencia Andaluza del Agua. Consejería de Medio Ambiente*. Junta de Andalucía. [online] URL accessed October 2015: http://www.juntadeandalucia.es/medioambiente/portal_web/agencia_andaluza_del_agua/participacion/publicaciones/rio_andarax.pdf

Martínez Alier, J., and Schlüpmann, K. 1987. *Ecological Economics: Energy, Environment, and Society*. Basil Blackwell, Oxford.

Marx, K., Mandel, E. 1970. *Capital: Volume 1: A Critique of Political Economy*. Reprint edition, Penguin Classics, London.

Mateo, S. 2013. *El modelo e horticultura intensiva de Almería ante la crisis actual. Una visión desde las modernas teorías del crecimiento económico*. Cajamar Caja Rural, Almería.

Maturana, H.R., and Varela, F.J. 1980. *Autopoiesis and cognition: the realization of the living*. Boston studies in the philosophy of science 42. D. Reidel Pub. Co, Dordrecht and Boston.

Mayumi, K. 1995. Nicholas Georgescu-Roegen (1906-1994): An admirable epistemologist. *Structural Change and Economic Dynamics* 6:261–265.

Mayumi, K., and Giampietro, M. 2006. The epistemological challenge of self-modifying systems: Governance and sustainability in the post-normal science era. *Ecological Economics* 57:382–399.

McMichael, P. 2011. Food system sustainability: Questions of environmental governance in the new world (dis)order. *Global Environmental Change* 21:804–812.

Meadows, D.H., Meadows, D.L., and Randers, J. 1972. *Limits to growth*. Universe books, New York.

Medeazza, G. 2008. *Escasez de agua dulce y desalinización: Los casos de Marruecos, Lanzarote (España), Palestina y el sur de la India*. Bakeaz/FNCA, Bilbao.

Medgal, S.B., Smith, Z.A., and Lien, A.M. 2008. *Evolution and Evaluation of the Active Management Area Management Plans*. Report of the Water Resources Research Center.

Medgal, S.B., and Lien, A.M. 2008. *Tucson Regional Water Planning Perspectives Study.* Report of the Water Resources Research Center.

Megdal, S.B., Dillon, P., and Seasholes, K. 2014. Water Banks: Using Managed Aquifer Recharge to Meet Water Policy Objectives. *Water* 6:1500-1514.

Megdal, S.B. 2015. Interview.

Menzel, L., and Matovelle, A. 2010. Current state and future development of blue water availability and blue water demand: A view at seven case studies. *Journal of Hydrology* 384(3-4):245–263.

Merkx, F., van der Weijden, I., Oostveen, A.M., van den Besselaar, P., and Spaapen, J. 2007. *Evaluation of Research in Context. A Quick Scan of an Emerging Field*. Rathenau Instituut - Department Science System Assessment. [online] URL accessed October 2015: http://www.rathenau.nl/uploads/tx_tferathenau/ERiC_quick_scan_1__01.pdf

MARM - Ministerio de Medio Ambiente, Medio Rural y Marino. 2008. *Instrucción de planificación hidrológica*. ORDEN ARM/2656/2008. Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid, Spain. [online] URL accessed August 2015: http://www.sghn.org/Normativa_ambiental/Auga_Humidais/Orden_ARM_2656_2008_Instruccion_Planificacion_Hidrologica.pdf

Mishan, E. 1993. *The Costs of Economic Growth*. Revised Edition, Praeger, Westport, Conn.

Mix, K., Lopes, V. L., and Rast, W. 2014. A Systems Approach to Understanding the Evolution of the Agro-Social-Ecological System of the Upper Rio Grande-San Luis Valley, Colorado. *Water Resources Management* 29(2):233–251.

Molden, D., Vithanage, M., de Fraiture, C., Faures, J.M., Gordon, L., Molle, F., and Peden, D. 2011. Water Availability and Its Use in Agriculture. In Wilderer, P. (Ed.) *Treatise on Water Science* 707–732. Elsevier, Oxford.

Molle, F. 2006. Planning and managing water resources at the river-basin level: emergence and evolution of a concept. In *Comprehensive Assessment of Water Management in Agriculture*, Research report 16. International Water Management Institute, Colombo.

Molle, F. 2008a. Nirvana Concepts, Narratives and Policy Models: Insights from the Water Sector. *Water Alternatives* 1(1):131–156.

Molle, F. 2008b. *Can Water Pricing Policies Regulate Irrigation Use?* Proceedings of the 13th World water Congress, 1-4 September 2008, Montpellier, France.

Molle, F. 2011. *Aquifer Safe Yield : Hard Science or Boundary Concept?* Proceedings of Ground Water 2011 Conference, March 2011, Orléan, France. [online] URL accessed September 2015: http://www.documentation.ird.fr/hor/fdi:010051839.

Molle, F., and Mollinga, P. 2003. *Water poverty indicators: conceptual problems and policy issues*. [online] URL accessed August 2015: http://www.iwaponline/wp/00505/wp005050529.htm.

Molle, F., Mollinga, P. and Wester, P. 2009. Hydraulic Bureaucracies and the Hydraulic Mission: Flows of Water, Flows of Power. *Water Alternatives* 2(3):328–349.

Mollinga, P. 2008. Water, Politics and Development: Framing a Political Sociology of Water Resources Management. *Water Alternatives* 1(1):7–23.

Montanari, A. 2011. 2.17 - Uncertainty of Hydrological Predictions. In Wilderer, P. (Ed.) *Treatise on Water Science*, 459–478. Elsevier, Oxford.

Morin, E. 1994. *Introducción al pensamiento complejo.* Gedisa, Barcelona.

Moyano, E., and Garrido, F. 2009. El regadío y la política de desarrollo rural. In *La economía del agua de riego en España,* 383–404. Cajamar Caja Rural, Sociedad Cooperatica de Crédito.

Müller, F., Hoffmann-Kroll, R., and Wiggering, H. 2000. Indicating ecosystem integrity — theoretical concepts and environmental requirements. *Ecological Modeling* 130(1-3):13–23.

Müller, F., and Nielsen, S.N. 2008. Emergent Properties. In *Systems Ecology*, 1212-1217. Elsevier B.V.

Munda, G. 2004. Social multi-criteria evaluation: Methodological foundations and operational consequences. *European Journal of Operational Research* 158(3):662–677.

Murdoch, J. 2003. Co-constructing the countryside: hybrid networks and the extensive self. In Cloke, P. (Ed) *Country Visions*, 263–282. Pearson, London.

Murphy, K. 2012. The social pillar of sustainable development: a literature review and framework for policy analysis. *Sustainability Science, Practice and Policy* 8(1):15–29.

Naredo, J.M. 2006. *Raíces económicas del deterioro ecológico y social*. Siglo XXI de España, Madrid.

Nicolis, G., and Prigogine, I. 1989. Exploring complexity: an introduction. W.H. Freeman, New York.

NWS-NOAA - National Weather Service Forecast Office, Tucson, Arizona. [online] URL accessed February 2015: http://www.wrh.noaa.gov/twc/climate/tus.php

O'Riordan, T. 2012. On social sustainability in a world of limits facing prolonged austerity. *Sustainability Science, Practice and Policy* 8(1):1–2.

Odum, H.T. 1971. *Environment Power and Society*. Wiley- Interscience, New York.

Odum, H.T. 1983. *Systems Ecology*. Wiley, New York.

OECD (Ed.) 2011. *Divided we stand: why inequality keeps rising*. OECD, Paris.

Ostrom, E. 2005. *Undersanding Institutional Diversity*. Princeton University Press., New Haven.

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences* 104(34):15181–15187.

Ostwald, W. 1907. The modern theory of energetics. *Monst* 17:481-515.

Ostrom, E. 2009. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325(5939):419–422.

Padowski, J.C., and Jawitz, J.W. 2012. Water availability and vulnerability of 225 large cities in the United States. *Water Resources Research* 48(12):1944–7973.

PAG - Pima Association of Governments. (2012) *Shallow groundwater areas in Eastern Pima County*. [online] URL accessed February 2015: https://www.pagnet.org/documents/water/SGWAReport2012.pdf

Pahl-Wostl, C. 2009. A conceptual framework for analyzing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change* 19:354–365.

Pahl-Wostl, C., Conca, K., Kramer, A., Maestu, J., and Schmidt, F. 2013. Missing Links in Global Water Governance: a Processes-Oriented Analysis. *Ecology and Society* 18(2):33.

Pahl-Wostl, C., Holtz, G., Kastens, B., and Knieper, C. 2010. Analyzing complex water governance regimes: the Management and Transition Framework. *Environmental Science & Policy* 13(7):571–581.

Pahl-Wostl, C., Jeffrey, P., Isendahl, N., and Brugnach, M. 2011. Maturing the New Water Management Paradigm: Progressing from Aspiration to Practice. *Water Resources Management* 25(3):837–856.

Pahl-Wostl, C., Lebel, L., Knieper, C., and Nikitina, E. 2012. From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science & Policy* 23:24–34.

Parés, M. 2011. River Basin Management Planning with Participation in Europe: From Contested Hydro-politics to Governance-Beyond-the-State. *European Planning Studies* 19(3):457–478.

Parish, E.S., Kodra, E., Steinhaeuser, K., and Ganguly, A.R. 2012. Estimating future global per capita water availability based on changes in climate and population. *Computer & Geosciences* 42:79–86.

Pataki, D.E., Boone, C.G., Hogue, T.S., Jenerette, G.D., McFadden, J.P., and Pincetl, S. 2011. Socio-ecohydrology and the urban water challenge. *Ecohydrology* 4(2):341–347.

Pattee, H.H. 1973. *Hierarchy Theory: The Challenge of Complex Systems*. George Braziller, New York.

Pedregal, B., Cabello, V., Hernandez-Mora, N., Limones, N., and del Moral, L. 2015. Information and Knowledge for Water Governance in the Networked Society. *Water Alternatives* 8(2):1–19.

Pereira, A.G. and Funtowicz, S. 2006. Knowledge representation and mediation for transdisciplinary frameworks: tools to inform debates, dialogues & deliberations. *International Journal of Transdisciplinary Research* 1(1):34–50.

Poff N.L., Richter, B.D., Aarthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'Keeffe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., and Warner, A. 2010. The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards. *Freshwater Biology* 55(1):147–170.

Post, D.A., Chiew, F.H.S., Teng, J., Viney, N.R., Ling, F.L.N., Harrington, G., Crosbie, R.S., Graham, B., Marvanek, S., and McLoughlin, R. 2012. A robust methodology for conducting large-scale assessments of current and future water availability and use: A case study in Tasmania, Australia. *Journal of Hydrology* 412–413:233–245.

Potter, C., and Lobley, M. 2004. Agricultural restructuring and state assistance: competing or complementary rural policy paradigms? *Journal of Environmental Policy & Planning* 38(1):3–18.

Potter, C., and Tilzey, M. 2007. Agricultural multifunctionality, environmental sustainability and the WTO: Resistance or accommodation to the neoliberal project for agriculture? *Geoforum* 38(6):1290–1303.

Price, M.F. 1990. Humankind in the biosphere: The evolution of international interdisciplinary research. *Global Environmental Change* 1:3–13.

Prigogine, I. 1968. *Introduction to thermodynamics of irreversible processes*. Interscience Publishers.

Prigogine, I. Stengers, I., 1985. *Order out of chaos: man's new dialogue with nature*. Flamingo, London.

Pulido-Bosch, A., and Ben-Sbih, Y. 1995. Centuries of artificial recharge on the southern edge of the Sierra Nevada (Granada, Spain). *Environmental Geology* 26:57–63.

Ramos-Martin, J., Giampietro, M., and Mayumi, K. 2007. On China's exosomatic energy metabolism: An application of multi-scale integrated analysis of societal metabolism (MSIASM). *Ecological Economics* 63:174–191.

Rathwell, K.J., and Peterson, G. D. 2012. Connecting social networks with ecosystem services for watershed governance: a social-ecological network perspective highlights the critical role of bridging organizations. *Ecology and Society* 17(2):24.

Ravetz, J.R, and Funtowicz, S. 1993. Science for the Post-Normal Age. *Futures* 25(7):739-755.

Reisner, M. 1993. *Cadillac Desert: The American West and Its Disappearing Water*. Rev. and updated, Penguin Books, New York.

Resillience Alliance. 2010. *Assessing resilience in social-ecological systems: workbook for practitioners*. Version 2.0.

Rico-Amorós, A.M. 2010. Plan Hidrológico Nacional A.G.U.A: Repercusiones para las regiones de Murcia y Valencia. *Investigaciones Geográficas* 51:235–267.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J.A. 2009. A safe operating space for humanity. *Nature* 461:472–475

Romero, A., and Belmonte, F. 2008. *Erosión en forestaciones aterrazadas en medios semiáridos: Región de Murcia.* Editum, Universidad de Murcia, Murcia.

Romero, A., and Bermudez, F. 2009. *Soil erosion and desertification in neogene-quaternary basins of the Region of Murcia.* Fundación Instituto Euromediterráneo del Agua (IEA), Murcia.

Rosen, R. 1985. *Anticipatory systems: philosophical, mathematical, and methodological foundations*. Pergamon Press.

Rosen, R. 1991. *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*. Columbia University Press, New York.

Rosen, R. 2000. *Essays on Life Itself*. Columbia University Press, New York.

Roy, E.D., Morzillo, A.T., Seijo, F., Reddy, S.M.W., Rhemtulla, J.M., Milder, J.C., Kuemmerle, T., and Martin, S.L. 2013. The Elusive Pursuit of Interdisciplinarity at the Human–Environment Interface. *BioScience* 63(9):745–753.

Rulli, M.C., Saviori, A., and D'Odorico, P. 2013. *Global land and water grabbing*. PNAS 201213163.

Salinas, J.A. 2010. El Andarax: Aguas Superficiales. In Martinez, M. and Usero, S. (Eds.) *Río Andarax,* 223-231. Agencia Andaluza del Agua, Sevilla.

Sampedro, D., and del Moral, L. 2014. Tres décadas de política de aguas en Andalucía. *Cuadernos Geográficos* 53(1):36–67.

Sanchez, V. 2010. El Andarax: Una singularidad del sureste. In Martinez, M. and Usero, S. (Eds.) *Río Andarax* , 10-27. Agencia Andaluza del Agua, Sevilla.

Sanchez-Martos, F., Pulido-Bosch, A., Vallejo, A., Gisbert, J. and Molina, L. 2005. Hydrogeochemical aspects about the interaction groundwater-surface water in the Andarax river (Almería). *Geogaceta* 37:91–94.

Sanchez-Martos, F., Benito, G.,Casas-Casas, J., Frances-Herrera, I. Gisbert-Gallego, J., Molina-Sanchez, L., Pulido-Bosch, A., Vallejos-Izquierdo, A., and Zapata-Sierra, A. 2013. *Caracterización y evaluación de los factores hidrogeológicos, hidrológicos y antrópicos que condicionan la dependencia aguas superficiales-subterraneas en el río Andarax (Almeria)*. Proceedings of the X Simposio en Hidrogeología. Instituto Geológico y Minero Español. 16- 18 October 2013. Granada, Spain.

Sánchez-Picón, A., Aznar-Sánchez, J.A., and García-Latorre, J. 2011. Economic cycles and environmental crisis in arid southeastern Spain. A historical perspective. *Journal of Arid Environments, Deserts of the World Part IV: Iberian Southeast* 75:1360–1367.

Sauri, D., and del Moral, L. 2001. Recent developments in Spanish water policy. Alternatives and conflicts at the end of the hydraulic age. *Geoforum* 32(3):351-361.

Savenije, H.H.G., Hoekstra, A.Y., and van der Zaag, P. 2013. Evolving water science in the Anthropocene. *Hydrology and Earth Systems Sciences* 10(6):7619–7649.

Scheidel, A. 2013. *New Challenges in Rural Development: A Multi-Scale Inquiry into Emerging Issues, Posed by the Global Land Rush*. PhD Thesis. Ph.D. Program in Environmental Science and Technology. Universitat Autònoma de Barcelona.

Scholz, R.W., and Binder, C.R. 2011. *Environmental Literacy in Science and Society: From Knowledge to Decisions*. Cambridge University Press, Cambridge.

Scholz, R.W., and Binder, C.R. 2003. *The paradigm of human-environment systems*. Working Paper 37. Natural and Social Science Interface. Swiss Federal Institute of Technology, Zürich.

Schrödinger, E. 1983. *What is life? the physical aspect of the living cell*. Reprint. ed. Cambridge Univertsity Press, Cambridge.

Segura, D. 2010. Usos y aprovechamientos tradicionales del agua. In M. Martinez & S. Usero (Eds.) *Rio Andarax,* 249–256. Agencia Andaluza del Agua, Sevilla.

Serrano-Tovar, T. and Giampietro, M. 2014. Multi-scale integrated analysis of rural Laos: Studying metabolic patterns of land uses across different levels and scales. *Land Use Policy* 36:155–170.

Serrano-Tovar, T. 2014. *Spatial Analysis in MuSIASEM. The use of Geographic Information Systems and Land Use applied to the integrated analysis of rural systems' metabolism*. PhD Thesis. Ph.D. Program in Environmental Science and Technology. Universitat Autònoma de Barcelona.

Serrat-Capdevila, A., Cabello, V., Boyanova, K., Poupeau, F., Rodriguez, D., Salmoral, G., Segura, S., and Yang, Z. 2014. *Analyzing New Challenges for Water Management: An outline for a trans-disciplinary approach, based on a review of existing conceptual frameworks*. Deliverable 5, Supplement 1. Sustainable Water Action –SWAN- EU Incolab FP7 project. [online] URL accessed October 2015: http://swanproject.arizona.edu/sites/default/files/Deliverable_5_Supplement1_web.pdf

Simon, H.A. 1962. The Architecture of Complexity. *Proceedings of the American Philosophical Society* 106(6):467–482.

Sivakumar, B. 2012. Socio-hydrology: not a new science, but a recycled and re-worded hydrosociology. *Hydrological Processes* 26(24):3788–3790.

Sivapalan, M., Konar, M., Srinivasan, V., Chhatre, A., Wutich, A., Scott, C.A., Wescoat, J.L., and Rodríguez-Iturbe, I. 2014. Socio-hydrology: Use-inspired water sustainability science for the Anthropocene. *Earth's Future* 2(4):2013EF000164.

Sivapalan, M., Savenije, H.H.G., and Blöschl, G. 2012. Socio-hydrology: A new science of people and water. *Hydrological Processes* 26(8):1270–1276

Smettem, K.R.J. 2008. Welcome address for the new "Ecohydrology" Journal. *Ecohydrology* 1(1):1–2.

Sophocleous, M. 1997. Managing Water Resources Systems: Why "safe Yield" Is Not Sustainable. Ground Water 35(4): 561–561.

Stefano, L.D. 2010. International Initiatives for Water Policy Assessment: A Review. Water Resour. Manag. 24, 2449–2466. Stutz, J. 2012. Response to Creating the future we want. *Sustainability Science, Practice and Policy* 8(2):76–78.

Subirats, J., Knoepfel, P., Larrue, C., and Varone, F. 2008. *Análisis y gestión de políticas públicas*. Ariel, Barcelona.

Swyngedouw, E. 1999. Modernity and Hybridity: Nature, Regeneracionismo, and the Production of the Spanish Waterscape, 1890-1930. *Annals of the Association of American Geographers* 89(3): 443–65.

Swyngedouw, E. 2006. Circulations and metabolisms: (Hybrid) Natures and (Cyborg) cities. *Science as Culture* 15(2):105-121.

Swyngedouw, E. 2010. Impossible Sustainability and the Post-political Condition. In Cerreta, M., Concilio, G., Monno, V. (Eds.) *Making Strategies in Spatial Planning,* 185–205. Springer Netherlands, Dordrecht.

Swyngedouw, E. 2013. Into the Sea: Desalination as Hydro-Social Fix in Spain. *Annals of the Association of American Geographers* 103 (2): 261–70.

SYTF - Safe Yield Task Force. 2015. January meeting. Tucson Metropolitan Water District. Tucson, Arizona.

Tovey, H. 2009. Sustainability: A Platform for Debate. *Sustainability* 1(1):14–18

Truelove, M. 1992. Measurement of spatial equity. *Environment and Planning C: Government and Policy* 11:19-34.

Tucson Water. 2013. *ADWR Enhance Aquifer Management- Evaluation comment*. [online] URL accessed February 2015: http://www.azwater.gov/azdwr/WaterManagement/AMAs/EnhancedAquiferManagementStakeholderGroup.htm

Turton, A.R., and Ohlsson, L. 1999. Water Scarcity and Social Stability: Towards A Deeper Understanding of the Key Concepts Needed To Manage Water Scarcity in Developing Countries. Presented at the 9th Stockholm Water Symposium, Stockholm, Sweden.

Ulanowicz, R.E. 1986. *Growth and Development: Ecosystem Phenomenology*. Springer-Verlag, New York.

Ulanowicz, R.E. 1997. *Ecology, the Ascendent Perspective*. Columbia University Press, New York.

Van Asselt, M.B.A. 2000. *Perspectives on Uncertainty and Risk*. Springer Netherlands, Dordrecht.

Van Cauwenbergh, N., Pinte, D., Tilmant, A., Frances, I., Pulido-Bosch, A., and Vanclooster, M. 2008. Multi-Objective, Multiple Participant Decision Support for Water Management in the Andarax Catchment, Almeria. *Environmental Geology* 54 (3):479–89.

Van Cauwenbergh, N., and Ballester, A. 2015. "Participatory Processes and Supportive Tools for Planning in Complex Dynamic Environments: A Case Study on Web-GIS Based Participatory Water Resources Planning in Almeria (Spain)" *Environment and Planning B* (In press).

Venot, J.P., Molle, F. Hassan, Y. and International Water Management Institute. 2007. *Irrigated Agriculture, Water Pricing and Water Savings in the Lower Jordan River Basin*. International Water Management Institute, Colombo.

Vogel, R.M., Lall, U., Cai, X., Rajagopalan, B., Weiskel, P., Hooper, R.P., and Matalas, N.C. 2015. Hydrology: The interdisciplinary science of water. *Water Resources Research* 51(6): 4409–4430.

Von Foerster, H. 1981. *Observing systems*. Intersystems Publ., Salinas.

Vörösmarty, C. J., Pahl-Wostl, C. and Bhaduri, A. 2013a. Water in the anthropocene: New perspectives for global sustainability. *Current Opinions in Environmental Sustainability. Aquatic and marine systems* 5(6):535–538.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., and Davies, P.M. 2010. Global threats to human water security and river biodiversity. *Nature* 467(7315):555–561.

Vörösmarty, C.J., Pahl-Wostl, C., Bunn, S.E., and Lawford, R. 2013b. Global water, the anthropocene and the transformation of a science. *Current Opinions in Environmental Sustainability. Aquatic and marine systems* 5(6):539–550.

Walker, B., Carpenter, S., Anderies, J.M., Abel, N., Cumming, G.S., Janssen, M.A., Lebel, L., Norberg, J., Peterson, G.D., and Pritchard, R. 2002. Resilience Management in Social-ecological Systems: a Working Hypothesis for a Participatory Approach. *Conservation Ecology* 6(1):14.

Waterstones, M. 1992. Of dogs and tails: water policy and social policy in Arizona. *Water Resources Bulletin. America Water Resources Association* 28(3)479-486.

White, L.A. 1943. Energy and the evolution of Culture. *American Anthropologist* 45(3):335–356.

Wiener, N. 1948. *Cybernetics or Control and Communication in the Animal and the Machine.* Second edition, MIT Press, Cambridge.

Willaarts, B.A., Volk, M. and Aguilera, P.A. 2012. Assessing the ecosystem services supplied by freshwater flows in Mediterranean agroecosystems. *Agricultural Water Management* 105:21–31.

Wilson, N., and Needham, R. 2006. *Groundwater Conservation Policy in Agriculture*. Proceedings of the 6th Conference of the International Association of Agricultural Economists Gold Coast Convention & Exhibition Centre. Queensland, Australia.

WISPS - Water and Wastewater Infrastructure, Supply and Planning Study. 2010. *2011-2015 Action Plan for sustainable water action.* [online] URL accessed February 2015: http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=135647

WFD – Water Framework Directive 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy. [online] URL accessed February 2015: http://ec.europa.eu/environment/water/water-framework/index_en.html.

Wolfram, S. 2002. *A New Kind of Science*. Wolfram Media, Champaign.

Woods, M. 2007. Engaging the Global Countryside: Globalization, Hybridity and the Reconstitution of Rural Place. *Progress in Human Geography* 31(4):485–507.

Young, O.R., Berkhout, F., Gallopin, G.C., Janssen, M.A., Ostrom, E., and van der Leeuw, S. 2006. The globalization of socio-ecological systems: An agenda for scientific research. *Global Environmental Change* 16:304–316.

Zhou, Y. 2009. A Critical Review of Groundwater Budget Myth, Safe Yield and Sustainability. *Journal of Hydrology* 370(1–4):207-213.

Zimmermann, E. 1951. *World resources and industries: a functional appraisal of the availability of agricultural and industrial materials*. Harper.

Zipf, G.K. 1941. *National unity and disunity: the nation as a bio-social organism*. The Principia press, inc.

APPENDIX 1

Table A1. 1- *Characterization of WMSES as a framework for SES analysis according to the criteria of Binder et al. 2013*

Contextual criteria	
Acronym	WMSES
Disciplinary origin	Complexity Science, Sustainability Science, Bioeconomics, Systems Ecology
Theoretical origin	Complex systems theory, hierarchy theory, Rosen's modelling theory, autopoiesis, evolutionary theory, flow-fund model, Post-Normal Science, Multi-Scale Analysis of Societal and Ecosystem Metabolism
Application fields	Sustainability analysis, rural systems analysis, water use, analysis water-energy-food-land nexus, assessment of water management
Analytical purposes	Multi-scale and multi-dimensional analysis of resources use; integrated assessment of sustainability
Temporal scale	For societal systems: extent of one year, grain of hour. For ecological systems: extent of decades, grain of a year
Guidance/ operationalization	Guidance on operationalization is provided in several works depending on analytical purposes (Giampietro et al. 2014, Madrid 2014, Cabello et al. 2015)
Structural criteria	
Social system	
Scales	Multiple levels of societal organization, from whole social-ecological systems to functional compartments; semantically open definition of analytical levels and scales according to case study
Conceptualization and dynamics	Holarchy. Interactions intra and inter-holons. Impredicative loops. Processes and structures characterized through flow-fund model of Georgescu-Roegen 1971
Ecological system	
Scales	Multiple levels of eco-hydrological organization; semantically open definition of analytical levels and scales according to case study
Spatial scale	It has been applied at local, regional and national spatial extents and different grains. This dissertation focuses on the watershed extent and grains of water bodies and land uses and covers
Conceptualization and dynamics	Holarchy. Feedback relationships intra and inter-holons. Processes and structures characterized through eco-hydrological modeling and environmental impact assessment
Socio-Ecological system	
Conceptualization of interactions	Reciprocity between social systems and ecosystems characterized through four types of relationships describing the loop 'water supply->societal uses/discharges ->impacts on ecosystems->impacts on supply'.
Degree of equal depth	So far more focus on the social system. This dissertation proposes the analysis of ecosystem metabolism of water through eco-hydrology and environmental impact assessment
Analysis vs action oriented	So far analysis oriented but nexus applications evolving towards public policy design (see http://ceproec.iaen.edu.ec/curso-musiasem/)

REFERENCES

Binder, C.R., Hinkel J., Bots P.W.G., and Pahl-Wostl, C. 2013. Comparison of Frameworks for Analyzing Social-Ecological Systems. *Ecology and Society* 18(4):26.

Cabello, V., Willaarts, B., Aguilar, M., and del Moral, L. 2015. River basins as socio-ecological systems: linking levels of societal and ecosystem metabolism in a Mediterranean watershed. *Ecology and Society 20*(3):20.

Giampietro, M., Aspinall, R.J., Ramos-Martin, J., and Bukkens, S.G.F. 2014*. Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Us*e. Routledge Explorations in Sustainability and Governance. Routledge, New York.

Madrid, C. 2014. The water metabolism of socio-ecosystems. Epistemology, methods and applications. PhD Thesis. Ph.D. Program in Environmental Science and Technology. Universitat Autònoma de Barcelona.

APPENDIX 2

This appendix has the purpose of extending the methodological description of Chapter 2, including detailed calculation of variables and modeling validation.

Scales

Figure A2.1 shows the temporal and spatial levels used for the Upper Andarax grammar according to these constraints. We run the BalanceMED model on temporal monthly and spatial Hydrological Units (HU) resolutions. Results were aggregated to the extents of one year and land uses and covers types. Socioeconomic data are available for a variety of grains (see Table 1). Human activity is mapped for whole urban areas (municipal level) and agricultural land uses for irrigation communities and rain-fed agriculture polygons. Note that we could do a municipal level analysis (comparing each municipality Land-Human activity budgets) but this would enlarge the amount of results and loose the purpose of the study: the operationalization of the SESWM framework for the analysis of water management at river basin scale. As Schneiel 2013 explains "every kind of data collection is always a 'heroic simplification' of a complex rural system and the issue is rather to find the adequate simplification, which allows answering some relevant research question". A more detailed hydrological resolution and, especially, temporal series of water use would clearly improve the method analytical potential.

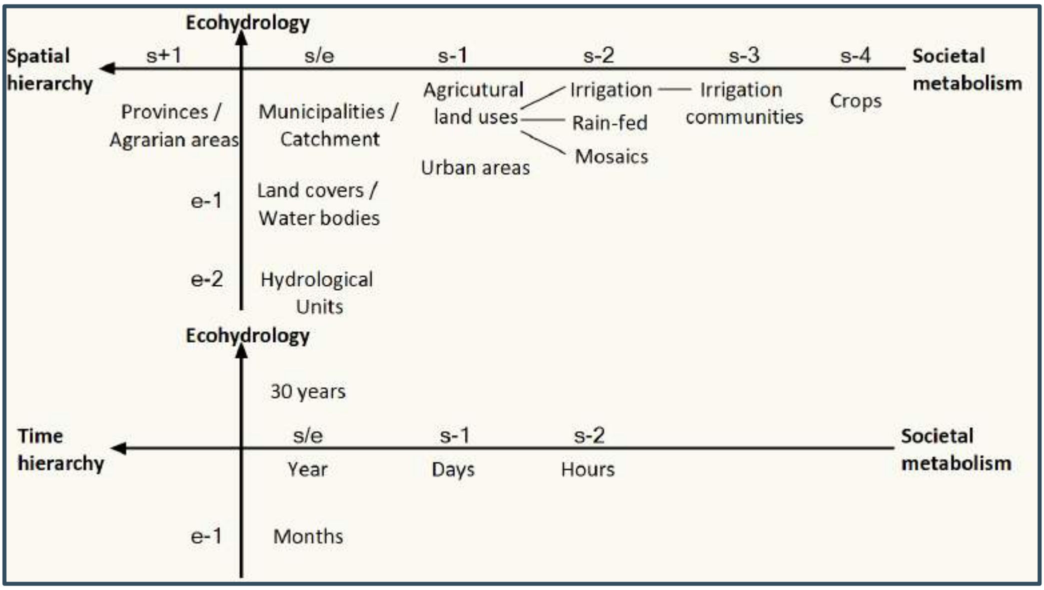


Figure A2. 1 - Temporal and spatial hierarchies in the Upper Andarax water grammar

Conceptual model and formal categories

The conceptual model for variables calculation is presented in Figure 2 and the formal categories of the grammar in Table 1. Codes and databases can be downloaded here: https://www.dropbox.com/sh/45za6hqmnjelqoi/AAD-ObuilYtGzFwVKyJ_WzQ5a?dl=0

BalanceMED

Precipitation and potential evapotranspiration

GIS raster layers of average monthly precipitation and potential evapotranspiration (PE) variables were obtained from the Andalusian Network for Environmental Information (REDIAM) for the period 1971-2000. Monthly scale reflects better the normal Mediterranean environmental conditions due to the usual lack of rainfall in finer time scales generated by long periods of water deficit. This source of information was chosen because it is the same used by the River Basin Authority for hydrological modeling. We found hydrological variables (runoff and recharge) were greatly overestimated using this data source. Mean values are usually not representative when dealing with very irregular regimes with skewed precipitation density functions such as the ones in the Andarax. In arid and semiarid climates, the median as central statistic measure is more robust. For this reason, median monthly values of were obtained at the closer 24 meteorological stations with available data for the 1971-2000 period (within a buffer of 10 km). These stations belong to the Spanish State Agency of Meteorology and only provide temperature and rainfall data. PE was estimated using an excel macro based on Thornthwaite method (HydroBio3, Camara and Martinez 2002). All data series where then spatialized using the Inverse Weighted Distance interpolation in ArcGIS 10.2 to obtain continuous information to be entered in the model. Results significantly improved making estimates closer to real conditions.

Hydrological units processing

Hydrological units are obtained from the intersection of soil and land cover GIS layers. Previously, several parameters were calculated for each of them. Roots depth, Leaf Area Index and interception capacity were gathered for vegetation species through literature review. Weighted means per number of species were obtained for each land cover unit. Soil parameters are wilting point, field capacity and soil depth. These are calculated from data on lime, clay and organic matter fractions extracted from the soil cartography of the Desertification Prevention in the Mediterranean Project (LUCDEME) of the Spanish Ministry of Agriculture.

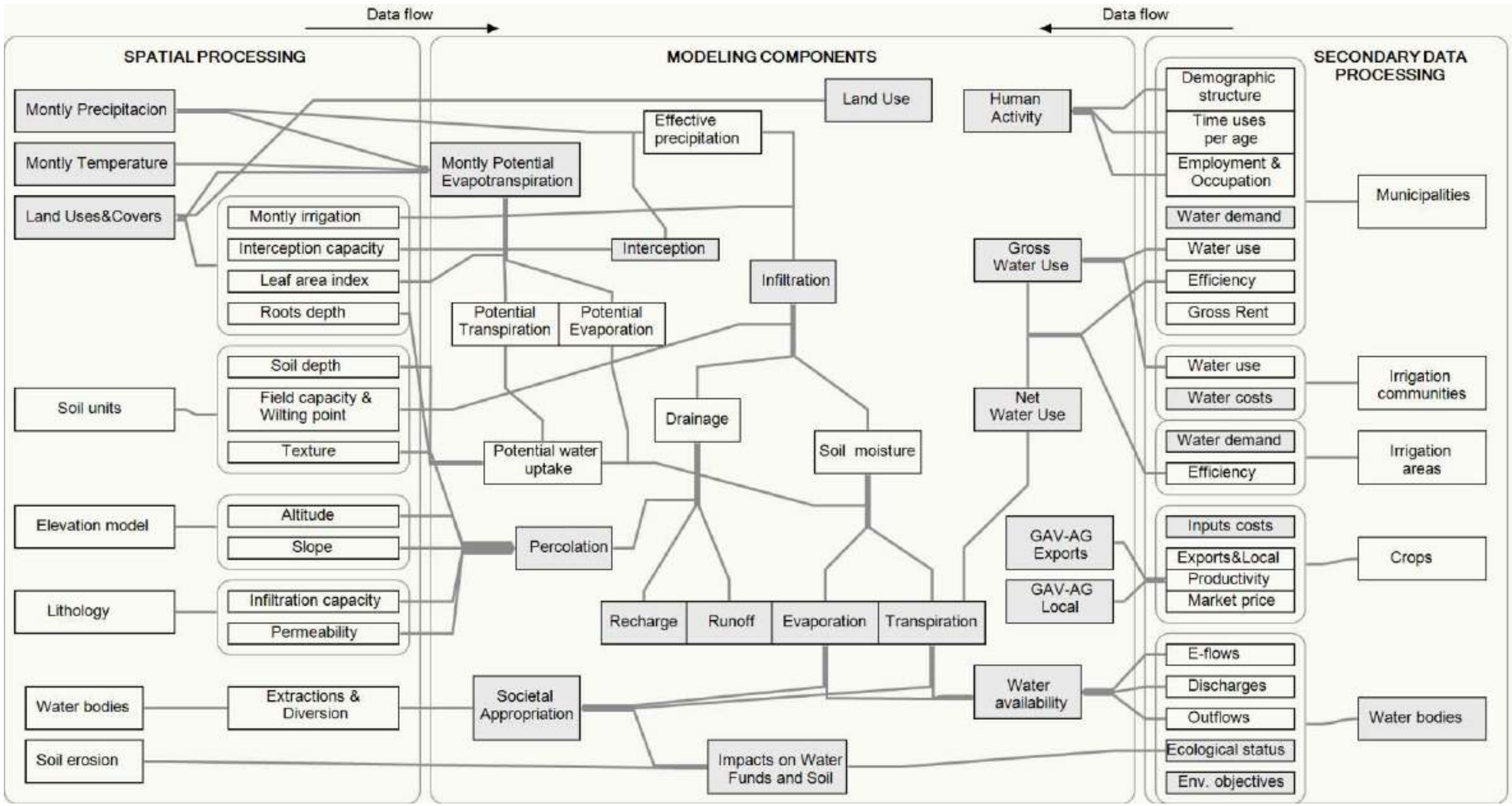


Figure A2. 2 - Conceptual scheme for water grammar formalization

Table A2. 1- Formal categories of the water grammar

Semantic categories	Types	Description	Units	Temporal resolution	Spatial resolution	Data sources
Water exchange						
Climate	Precipitation	Average precipitation from the series 1970-71/2000-01	mm/Hm^3	Months	Raster 10 m	Secondary Climatic Stations National Network (8)
Water funds turnover	Runoff	Total runoff to surface water bodies	mm/ Hm^3		HU	BalanceMED
	Recharge	Infiltrated rain water that percolates to aquifers				BalanceMED, APPLIS recharge model
	Soil Infiltration	Infiltrated rain water that is evapotranspired or contributes to soil reserve				BalanceMED
Societal appropriation & Availability	Surface	Direct diversion from the river for human uses	Hm^3	Year	Municipalities &Irrigation communities	(1), (2), (3)
	Groundwater	Extractions from aquifer	Hm^3			
	Soil water	Soil moisture in land used by humans	mm/ Hm^3	Months	HU	BalanceMED
Gross water use	Withdrawn	Ground and surface water consumption	Hm^3	Months	Municipalities &Irrigation communities	(1), (2), (3)
	Soil	Evapotranspiration from land uses		Months	HU	BalanceMED
Net water use	Urban supply	Water supply*Efficiency in supply chain	Hm^3	Year	Municipalities	(1), (2)
	Food production	Water withdrawal for agriculture*Efficiency in supply chain*Efficiency of irrigation system + Transpiration from rain water		Months	Agricultural areas & Irrigation communities	(1), (4), (5)
	Forestry &*Esparto*	Transpiration from rain water		Year	Land cover polygons	BalanceMED

	gathering					
	Cattle	Surface water requirements + transpiration from rain water		Year	Watershed, land cover	(1), BalanceMED
	Loses	Gross Water Use minus Net Water Use		Year	Municipalities& irrigation areas	(1), (2), (3)
Water demand		Deficit for irrigation purposes in the RBMP		Year	Irrigation areas	(1)
Water rights		Authorized withdrawals from each water body		Year	Water bodies	(1)
Organization						
Semantic categories	**Types**	**Description**	**Units**	**Temporal resolution**	**Spatial resolution**	**Data sources**
Climate	Temperature	Average precipitation from the series 1970-2001	°C	Months	Raster 10 m	Secondary Climatic Stations Network (8)
Water bodies	Rivers	Descriptive category: water bodies types considered in the RBMP	-	6 years	6 years	(1)
	Aquifers					
Land covers		Surface occupied by land cover types	Hectares	4 years	Land cover polygons	Map of Land Uses and Covers of Andalusia 2003 (9)
Managed land uses		Surface occupied by land uses types under managed land	Hectares	4 years	Land use polygons	
Human activity	Physiological overhead	Hours devoted to personal care, eating, sleeping and dependent people time	Hours	Hours	Municipalities	Time Use Survey of Almeria province 2002/03 (10) Spanish Population and Households Census 2001 (11)
	Social, Leisure &Education	Hours devoted to traveling, leisure activities, education and volunteering				
	Unpaid work	Hours devoted to households work				
	Paid Work	Hours devoted to each type of paid work sector by the working population				

						Local population census 2005 and 2011 (10)
Technical capital	Hydraulic infrastructures	% of surface of irrigation communities supplied by acequias	%	Year	Crop types	(3)
	Irrigation technology	% of surface of irrigation communities with drip irrigation				(3)
Monetary exchange	Agricultural inputs& Water costs	Total expenditures of irrigated agriculture on water and other inputs	€		Crops types & Irrigation communities	(3), (7)
	Gross Added Value	Total income from local and external markets			Crops types	(3), (6)

(1) CMAT 2012. Andalusia Mediterranean River Basins Management Plan 2009-2015. [online] URL: http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.7e1cf46ddf59bb227a9ebe205510e1ca/?vgnextoid=6d3173f2c746a310VgnVCM2000000624e50aRCRD&vgnextchannel=0bb66af68bb96310VgnVCM1000001325e50aRCRD
(2) Martinez, J. 2011. Energy Footprint of the urban water supply in Almeria province.
(3) CA 2008. Inventory and characterization of irrigation in Andalusia. [online] URL: http://www.juntadeandalucia.es/agriculturaypesca/sigregadios/servlet/regadios
(4) Fundación Cajamar. 2004. Irrigation doses for intensive horticulture in Almeria.[online] URL: http://www.publicacionescajamar.es/series-tematicas/centros-experimentales-las-palmerillas/
(5) CA 2011. System of technical assistance to farmers of the Andalusian government. [online] URL: http://www.juntadeandalucia.es/agriculturaypesca/ifapa/sar
(6) CMAT 2006. Andalusia Multiterritorial Information System. [online] URL: http://www.juntadeandalucia.es/institutodeestadisticaycartografia/sima/index2.htm
(7) CA 2005. Annual statistics on agriculture and fishing of Andalusia. [online] URL: http://www.juntadeandalucia.es/agriculturaypesca/portal/servicios/estadisticas/estadisticas/agrarias/resumen-anual.html
(8) AEMET. Spanish State Agency of Meteorology. [online under payment] URL: http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos
(9) REDIAM. Andalusian Network for Environmental Information. [online] URL: http://www.juntadeandalucia.es/medioambiente/site/rediam
(10) IECA. Andalusian Statistical and Cartography Office. [online] URL: http://www.juntadeandalucia.es/institutodeestadisticaycartografia
(11) INE. Spanish Statistical Office. [online] URL: http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft20%2Fe242&file=inebase&L=0

Percolation

The APLIS equation was proposed by Andreo et al. 2004 for determining the average rate of recharge in carbonate aquifers. This rate is expressed in BalanceMED as a percentage of drainage for each hydrological unit and calculated as:

$$R(\%) = (A + S + 3L + 2I + S)/90$$

Where A is the Altitude, S is the Slope, L is the Lithology, I the preferential Infiltration layers and S the Soil. Punctuation categories are established for each variable between one (minimal influence in recharge) and ten (maximum influence). In our study, slope was corrected to zero for agricultural land uses in order to introduce the leveling effect of terraces. These parameters are averaged for HU grain.

Model calibration, validation and limitations

A detail description of BalanceMED can be found in Willaarts et al. 2012. For this study, the model was translated from a Microsoft Excel macro to an R script to gain flexibility for future implementations. Model calibration was done through standard hydrograph plot (Figure A2.3). Monthly volumetric runoff rates are recorded at the only one available gauging station in the basin for the time series 1971-2000. Mean-monthly values of observed runoff were contrasted against model runoff. The peak of runoff in April responds to the monthly precipitation pattern but is not observed in the gauging station likely because it is the month were irrigation starts and pools are filled with diversions from river.

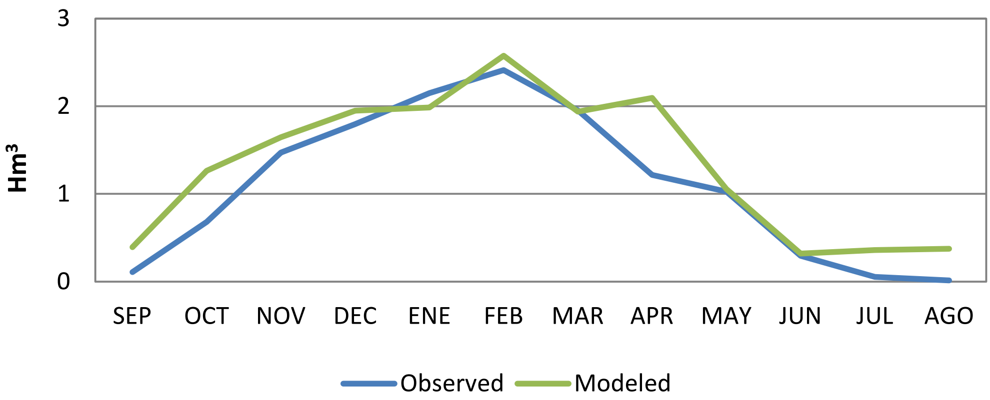


Figure A2. 3 - *Plot of observed vs modeled runoff volumetric rates*

In order to validate results, the evaluation statistics recommended by Moriari et al. 2007 were used: (i) the Nash-Sutcliffe efficiency (NSE) which indicates how well the plot of observed versus simulated data fits the 1:1 line, (ii) the Percent bias (PBIAS) which measures underestimation tendency of the model and (iii) the RMSE-observations standard deviation ratio (RSR), which is a standardized version of the root mean square error. The model performance can be judged as satisfactory according to these criteria (NSE > 0.50 and RSR < 0.70, and if PBIAS ≤25% for streamflow) (Table 2). The model efficiency shows a good plot fit between observed and simulated data. The PBIAS indicate a slight overestimation of runoff.

Table A2. 2- *Model evaluation of BalanceMED. Three metrics were calculated to validate modelresults: Nash-Sutcliffe efficiency (NSE) (range =−∞/1, optimum 1); Percent bias (PBIAS) (range =−∞/+∞, optimum 0); and RMSE-observations standard deviation ratio (RSR)(range =0/+∞, optimum 0)*

Statistics	Value
NSE	0.80
PBIAS	12.00
RSR	0.44

Post processing water grammar variables

Main results from BalanceMED are the volumetric variables of recharge, runoff, soil infiltration, transpiration and evaporation on a monthly and HU resolution. Intensive variables (mm or m^3/ha) used for spatial analysis of ecosystems-water funds relation are obtained by weighted means per area for each type of LULC considered. Extensive volumetric variables (total Hm^3) were obtained by aggregation per HU area.

Societal metabolism

Human activity

A thorough description of human activity accounting can be found in Kovacic and Ramos-Martin 2014. The Total Human Activity in a given society is calculated in hours as:

$$THA_{year\ i} = 365 * 24 * Population_{year\ i}$$

This total is disaggregated in subsequent hierarchical levels according to case-study objectives. In our case, the categories considered are explained in Table 1 and the equation to valid is:

$$THA_{2005} = HA_{PO} + HA_{SLE} + HA_{UW} + HA_{PW}$$

Where *PO* is physiological overhead; *SLE* is social, leisure and education; *UW* is unpaid work; *PW* is paid work. These variables were calculated for each municipality with data on employment, occupation, education and demographic structure from Spanish Census of Population and Households 2001 and the Time Use Survey 2002-03 for Almeria province. This latter establishes shares of hours devoted to the different activities in a day per age ranges. Since that information is only available every ten years in Spain, the obtained human activity shares were then extrapolated to the population evolution until 2005. Considering there was not mayor societal changes those years (pre economic crisis 2008 scenario), it is a reasonable assumption. The new census 2011 collected data from 2011 to 2013 and did not reach the same detailed level of municipality for required data inputs. For this reason it is not possible to update the human activity budget.

Land uses

Two geographical layers were used for the land budget analysis: the Map of Land Uses and Covers of Andalusia 2003 (MLUCV03) and the Inventory and characterization of irrigation in Andalusia 2008 (ICIA08). This latter collected data through surveys to Irrigation Communities from 2002 to 2008 and is the baseline used for the RBMP. It contains crops surface per irrigation community. Categories of irrigated agriculture in the MLUCV03 were coerced to match those of the ICIA08. For the rest of land uses and covers, we broke the hierarchical structure of the MLUCV03 in order to group them in types and levels relevant our analysis. MLUCV03 was intersected with the parks boundaries to obtained categories of land management. For each type of LULC and protection category (High protection in the National Park, Medium protection in the Natural Park, no protection in the rest of the watershed) a land use ratio was assigned as shown in Table A2.3.

Table A2. 3 - Land and soil water use coefficients

	High protection	Medium protection	Not protected	Water uses
Irrigated agriculture	1	1	1	Irrigated agriculture
Rainfed agriculture	1	1	1	Rainfed agriculture
Abandoned	0	0	0.2	Grazing
Quercus forest	0	0.1	0.2	Forestry
Pine plantations	0	0.1	0.2	Forestry
Riparian forest	0	0	0	
Shurbs	0	0.2	0.3	Grazing (2/3) and gathering (1/3)
Pastures	0	0.3	0.5	Grazing
Urban	0	1	1	Urban supply

Monetary flows and technical capital

Crops economic data and irrigation infrastructures were also double-sourced:

- Irrigated crops: Gross Added Value/ha, Working Days/ha, agriculture Inputs Costs/ha and Water Costs (cent €/m^3) were obtained from ICIA08. The type of trade (exports, local or self-consumption) and water supply and irrigation systems are also included in this database. Total extensive variables were obtained for each type of crop and trade.

- Rain-fed crops: production in Tons/ha per type of crops and prices received by farmers in €/100 kg were obtained from the annual statistics on agriculture and fishing of Andalusia 2005. Total Gross Added Value per crop was estimated based on the surface of rain-fed agriculture land uses.

There is no available data of added value for other economic activities than agriculture at municipal level. The total Gross Rent in the basin is calculated aggregating for each municipality rent per capita.

Water use

Water withdrawals and use were obtained from three sources:

- The Andalusia Mediterranean River Basins Management Plan 2009-2015, which includes extraction from different sources, water allocation to different uses and average irrigation efficiencies.
- The Inventory and characterization of irrigation in Andalusia 2008– ICIA08 contains data on gross water use for each irrigation community from different sources. Net water use was estimated by multiplying for the average efficiency in their area.
- The report from Martinez 2011 is the only data source with actual urban gross and net water use measured data for all municipalities in the Almeria province as well as water sources.

These variables are provided for one year. For seasonal analysis, monthly irrigation was estimated based on schedules from the technical assistance to farmers system of the Andalusian government and personal communication from farmers in the area. Multi-crops areas were averaged. Urban water was broken into equal monthly shares for residents and commercial uses and non-residential use was added to summer months. Water withdrawals were spatialized by splitting the river length in segments according to water withdrawal points by each municipality and irrigation community. Soil water use is calculated applying the same coefficients of land covers use and relating them to activities presented in Table 3. Gross water use is the total evapotranspiration and net water use is transpiration in those covers. The separation of transpiration from irrigation and from rain water was obtained by the difference between running the model with and without irrigation.

Environmental impacts

The assessment of the ecological status of water bodies is the baseline of the RBMP. Aquifers are evaluated on their quantitative (exploitation index) and qualitative (pollution) status. Rivers are evaluated on their biological (biodiversity), hydro-morphological and physic-chemical status. The information provided in the plan is rather dated (only one sampling campaign) and the final evaluation based on expert evaluation. We provide additional analysis of available secondary data to complement and discuss this assessment: erosion rates, water table levels and surface and groundwater quality.

The cartography of average erosion rates for the period 1992-2006 is available at the natural hazards section of the Andalusian Network of Environmental Information [Online] URL: http://www.juntadeandalucia.es/medioambiente/site/rediam/portada/. The calculation method used by the Andalusian Environment Agency is the Universal Soil

Loss Equation (USLE) and the scale set by this institution by normalizing the range of average soil loses values in the region from low (<12 ton/ha yr) to high (>50 ton/ha yr). Water table levels change was also averaged for the available series from 1992-2006 from the network of piezometers of the Spanish Institute of Geology and Mining Water Database [Online] URL: http://info.igme.es/BDAguas/. There are more control piezometers but only 32 have data and 22 data for the selected period. Most series stop in 2004 and there is no data afterwards in this database. The Spanish Ministry of Environment has been monitoring only 9 of them from 2006 on. The decrease in water table monitoring points is therefore considerable. Groundwater and surface water quality variables have been download from the Andalusian River Basins Network for physic-chemical and biological control of water quality, which contains all the sampling campaigns from 2002 to 2013 [Online] URL: http://laboratoriorediam.cica.es/Visor_DMA/?urlFile=http://laboratoriorediam.cica.es/Visor_DMA/service_xml/capas_dma.xml]. Available series for this period for each control point were averaged.

Regarding ecosystems water requirements, land ecosystems transpiration is a result from BalanceMED, environmental flows for the river are proposed in the RBMP on a monthly volumetric rate and aquifer discharges to springs and other connected aquifers were estimated in the Hydrogeological Atlas of Andalusia 1980-1990 [Online] URL: http://aguas.igme.es/igme/publica/libros1_HR/libro110/Pdf/lib110/in_32.pdf.

REFERENCES

Allen, T. F. H., and Hoekstra, T. W. 1992. *Towards a unified ecology*. Columbia University Press. New York.

Andreo, B., J. Vías, J. A. López-Jeta, F. Carrasco, J. J. Durán, and Jiménez, P. 2004. Propuesta metodológica para la estimación de la recarga de acuíferos carbonáticos. *Boletín Geológico Minero* 115:177–186.

Camara, R., and Martinez, B. 2002. HidroBio.V3.0. Plantilla para el cálculo del balance hídrico y el diagrama bioclimático: su aplicación a estudios de hidrología y geobotánica. Equipo de Trabajo Estudios Tropicales y Cooperación al Desarrollo del Grupo de Investigación Cuaternario y Geomorfología (PAI RNM-273). Departamento de Geografía Física y Análisis Geográfico Regional, Universidad de Sevilla.

Kovacic, Z., and Ramos-Martin, J. 2014. Accounting for human activity and socio-economic characteristics. In Giampietro et al (Eds.) *Resource Accounting for Sustainability Assessment: The Nexus between Energy, Food, Water and Land Use*. Routledge Explorations in Sustainability and Governance. Routledge, New York, New York, USA.

Madrid, C. , J.J. Cadillo-Benalcazar, F. Diaz-Maurin, Z. Kovacic, T. Serrano-Tovar, T. Gomiero, M. Giampietro, R. J. Aspinall, J. Ramos-Martin and Bukkens, S. G.F. 2014. Punjab state, India. In Giampietro et al (Eds.) *Resource Accounting for Sustainability Assessment: The Nexus between*

Energy, Food, Water and Land Use. Routledge Explorations in Sustainability and Governance. Routledge, New York, New York, USA .

Martinez, J. 2011. *Energy Footprint of the urban water supply in Almeria province*. [online] URL: http://repositorio.ual.es:8080/jspui/bitstream/10835/1152/1/Estudio%20de%20la%20Huella%20Energetica%20del%20Abastecimiento%20Urbano%20de%20Agua%20de%20la%20Provincia%20de%20Almeria_Martinez%20Rodriguez,%20Francisco%20Javier.pdf.

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and Veith, T. L. 2009. Model evaluation guidelines for systematic quantification of accuracy in watersheds simulations. *American Society of Agricultural and Biological Engineers* 50(3): 885−900.

Ravera F., Gamboa G., Scheidel A., Dell'Angelo J., Serrano T., Mingorría S., Cabello V., Ariza P., and Arizpe N. 2014. Pathways of rural change: An integrated Assessment of the metabolic patterns of emerging ruralities. *Environment Development and Sustainability* 16(4):1–10.

Scheidel, A. 2013. *From MuSIASEM theory to practice: report and reflections from field research in Kampot province, Cambodia Recer*. ICTA working paper Dipòs. Recer. Catalunya. [online] URL: http://www.recercat.net/handle/2072/209216.

Serrano-Tovar, T. and Giampietro, M.2014. Multi-scale integrated analysis of rural Laos: Studying metabolic patterns of land uses across different levels and scales. *Land Use Policy* 36:155–170.

Willaarts, B.A., M. Volk, and Aguilera P.A. 2012. Assessing the ecosystem services supplied by freshwater flows in Mediterranean agroecosystems. *Agricultural Water Management* 105:21–31.

APPENDIX 3

Synthesis of focus group on assessing water management in the Andarax. University of Almeria. Almería, May 29th , 2014.

During the ALTAGUAX project, a set of indicators for sustainability of water management assessment had been proposed. The indicators resulted from discussions in two workshops and were arranged in the three classical dimensions of sustainability.

This focus group was an excercise of assessment of water management in the Andarax basin. The session objectives were i) to assess opposed management strategies on one side; and ii) evaluate the information provided and methodology on the other. Fifteen invitations were sent to key stakeholders and 7 people attended including one representative from the gricultural sector, two from urban water supply, three from the academia and one from the New Water Culture Foundation. The representatives from the Mediterranean Andalusian River Basin District did not attend.

A baseline diagnosis of societal metabolism and sustainability indicators quantification was presented and discussed. Afterwards, the excercise of assessing management strategies was arranged in two groups, one for Alto Andarax and another for Bajo Andarax. The excercise consisted in valuating the change of the value of indicators on a qualitative basins, using a flag-multiscale template of Kovacic 2014. This template arranges indicators of the three dimenssions of sustainbility in different spatial and temporary scales. The first one are characterized by the levels on the left with an increasing spatial scale (n-1, n, n+1) and the latter by the differentiation between indicators of state and of performace. Each group had to evaluate two alternatives corresponding to opposed narratives identified in Chapter 4 under a number of explicit assumptions. However, the initial discussion about the baseline diagnosis raised a lot expectation and took more time than planned. In consequence, the assessment excercise could not be completed and only one alternative was appraised (Figures A3.1 and A3.2).

In what follows, I summarize what I consider the most interesting points of the discussion, including those of the final evaluation of the metabolism framework as a water accounting methodology. These reflections supported the discussion of analytical chapters in the Andarax and the final consclusions of this dissertation.

- The diagnose information on societal funds and water flows was considered useful and sufficient. Nevertheless, water funds data from the River Basin Management Plan 2009-2015 was not considered rigorous because the models used by the water administration are not properly calibrated.

- The lack of aquifer dynamic modeling is a clear drawback of the information provided, and of the hydrological information of the basin in general.
- Some attendees deemed the quantification of indicators as a form of objectification of the discussion, whereas others insisted on the idea of values underlying the indicators they proposed 4 years earlier.
- The Water Extraction Index is an essential indicator without standard calculation procedure that makes comparisons among studies impossible. It is necessary to incorporate an accurate assessment of environmental requirements in the index.
- The issue of appropriate scale for indicators calculation is central. Current scales used in the formal planning do not allow to link water uses with environmental impacts and a disaggregation into smaller levels would be advisable. The concepts of couple water-human systems and socio-ecological systems seem to fit in this requirement.
- The top-down approach of the WFD is questioned by some stakeholders as imposing environmental objectives that lack a thorough understanding of regional realities. They would prefer a combination of bottom-up and top-down approaches in water planning. On the other hand others advocated for a top-down coherent framework arguing that if contextual specificities are considered in water planning, the achievement of common environmental objectives will not be possible. This perception defends that ecological status assessment requires standardized protocols and the design process of the program of measures should be open to active public participation.
- The consideration of power relations was deemed essential in an assessment of sustainability. The lack of this analysis in the presented societal metabolism approach was considered a drawback of the method. The necessity of formal indicators to evaluate democratic quality, governance effectiveness and corruption was emphasized.
- The assessment method is considered useful for participatory discussions to achieve a common vision about where management strategies should be headed. Nevertheless, it is not detailed enough to go to smaller spatio-temporal scales of sustainability problems.

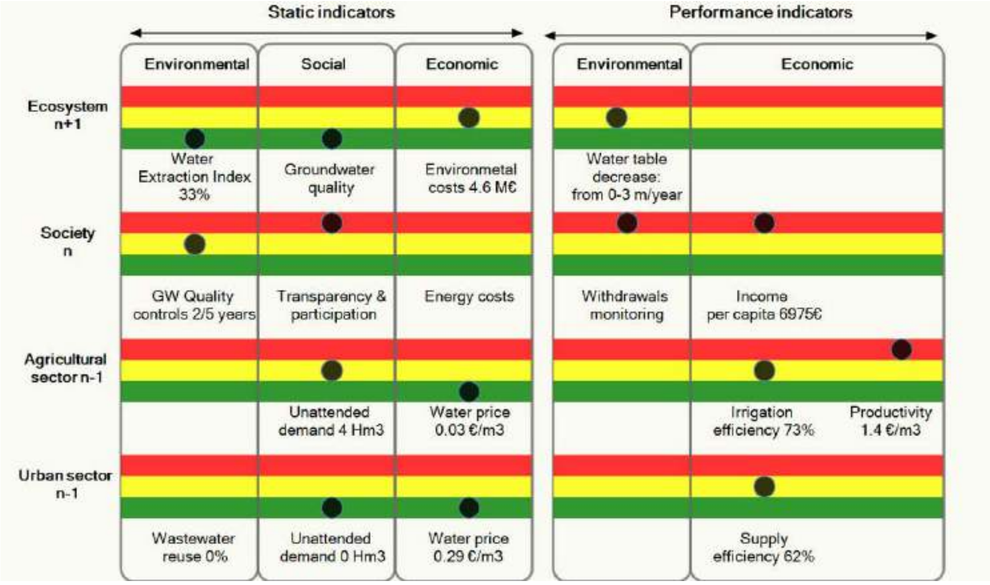


Figure A3. 1 *- Assessment of efficiency improvement in Alto Andarax*

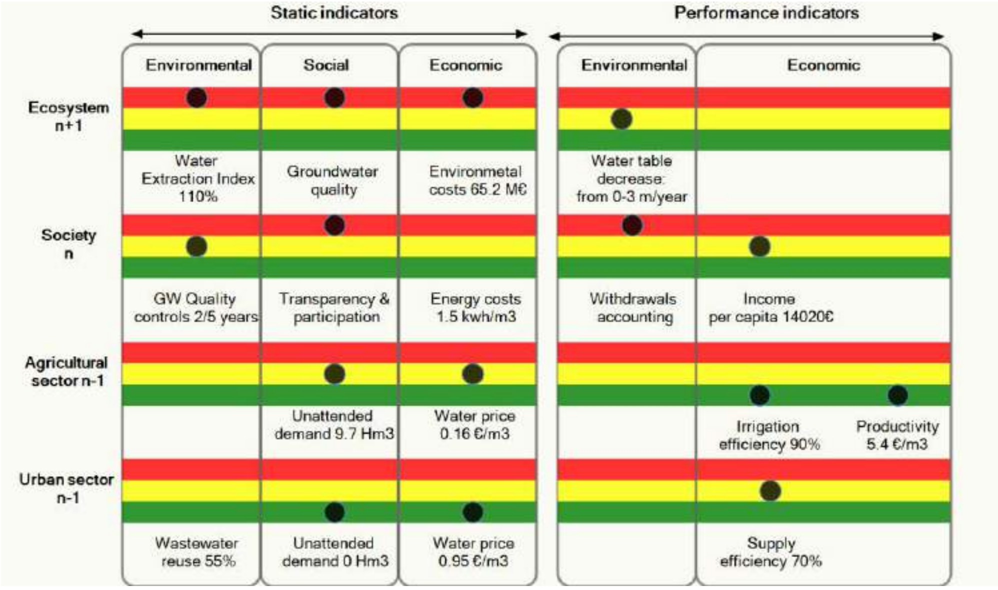


Figure A3. 2 *- Assessment of governance improvement in Bajo Andarax*

REFERENCES

Kovacic, Z. 2014. Assessing Sustainability: The Societal Metabolism of Water in Israel. *International journal of Performability Engineering* 10(4, Paper 6):387-399.

APPENDIX 4

Synthesis of the first SWAN Tucson basin stakeholders workshop. University of Arizona. Tucson, October 30th, 2013.

The primary goal of SWAN is to promote research links between the US and the EU through the development of a Transatlantic Dialogue on Water Governance. This goal is achieved through the collaboration on comparative analysis of water management issues in different case study locations in the EU and the USA. A Key component of SWAN is the development of research stays of European researchers at the iGlobes-UMI located in the University of Arizona.

During the spring semester of 2013 a group of international and US students who were conducting research stays at the University of Arizona either in association with SWAN or with University of Arizona SWAN-related faculty met weekly to develop a cooperative approach to trans-disciplinary research. The meetings were coordinated by UA Research faculty Aleix Serrat-Capdevila and Hoshin Gupta and were attended by University of Arizona SWAN-related faculty Francina Dominguez, Juan Valdés and UMI director Franck Poupeau. Their work had three specific outcomes:

- Institute the weekly meetings as the focus of the scientific cooperation building efforts.
- Agree to focus on the Tucson Active Management Area region as geographical area to realize the central case study and to develop a collaborative research on water management/ regulation.
- Set the groundwork for an academic paper on trans-disciplinary collaboration.

SWAN's scientific approach is built on ideas of the complexity and incommensurability associated with the management of social-ecological systems, as well as the need to deal with conflicts and politics unavoidably associated with environmental management. We recognize the uncertainty of model predictions in complex issues which implies the necessity of opening scientific outcomes to public validation. Therefore, any case-study based research must necessarily build on collaboration with stakeholders who are experts in the water management challenges of their region at different scales. The decision was therefore made to build a collaborative process with stakeholders intertwined with interdisciplinary research. This process was also intended to support the work of the students that will be conducting research stays at the University of Arizona in the framework of SWAN and minimize stakeholder fatigue.

Throughout the spring semester of 2013, in order to build this collaboration and start identifying key research questions for the Tucson Basin area, SWAN researchers met with Linda Stitzer (former Head of the Tucson AMA) and invited speakers at the April SWAN progress meeting, such as Ed Curley (Pima County), Ralph Mara (formerly in Tucson Water), Kathy Chavez (Pima County) and people from different academic institutions involved in stakeholder relevant projects. From these meetings initial research questions were identified and developed. Additionally, the decision was made to organize an initial workshop with local stakeholder experts in order to identify key areas of concern, validate research approaches, and start building a collaborative research process.

This first Stakeholder Workshop was organized on Wednesday, October 30th at the University of Arizona in the context of SWAN's Fourth Progress Meeting. Local experts, members of the UA academic community and SWAN researchers were invited to attend. The goal of the workshop was three-fold:

1. Indentify key management challenges in the Tucson basin region
2. Evaluate and prioritize the pre-defined research questions.
3. Identify knowledge gaps and propose new research questions.
4. Map a list of relevant Tucson basin region stakeholders.
5. Propose a roadmap for future collaboration.

The first SWAN Stakeholder workshop was designed for a group of 6-10 stakeholders. However, due to a variety of circumstances attendance to the workshop was limited. As it often happens with participatory research, there is a significant process of learn-as-you-go. The possibility of having an in-depth discussion with a small number of extremely knowledgeable and experienced stakeholders greatly facilitated the exchange of ideas and allowed for a rich and productive working session. As a result, it was decided that, to the extent possible, future interactions with local stakeholder-workshops will follow a similar pattern and be limited to working sessions with 2-3 stakeholders.

Identification of Key Management Challenges in the TAMA region

At the beginning of the workshop, participants were asked to write the single most important water management challenge in the Tucson basin from their perspective. The results are shown below grouped by type of participant:

<u>Stakeholders</u>

- ♦ Sustaining both human and natural systems with extremely variable water inputs (erratic rainfall, shifting human demands, etc.)
- ♦ Under pressure of population growth: balancing all water needs. In the context of

the TAMA rules: private wells, environmental needs, outdoor/indoor reuse (use changes), reclaimed water (new resources).

SWAN/Academia

- Aquifer overdraft.
- Drawdown of the water table (caused by drying up the rivers and riparian zones). Water availability in the face of growing population and likely decreasing supply.
- How to deal with the stream-flow decrease of Colorado River basin plus its impacts on CAP transfer.
- Disconnection between land & urban development and water management (after the joint study).
- Growth (human demand and perceptions/acceptability of variable water service and quality).
- Challenges on the M+I water supply due to climatic and legal constraints on the CAP water
- Maintaining ecosystems services in an urban environment.
- Water quality – specific odor due to over bleaching? Water scarcity, riparian ecosystems.

Research Concerns

During this activity participants were presented with a list of research questions that had been identified during the SWAN weekly meetings. The activity was divided into three parts:

- Rate the relevance of the different questions by placing colored dots next to those they considered most significant.
- Propose new research questions based on the perceived knowledge gaps in the TAMA region. The results of this third activity are presented in section 4 below.
- Discussion about the relevance of the questions;

Evaluation and Prioritization of Research Questions

Participants were given a list of proposed research questions and 12 colored dots (red for stakeholders and blue for other participants). Questions had also been placed on the wall on large cards and grouped by categories. Participants were given 10 minutes to read the questions and assess their relevance by placing the dots on the most significant/relevant ones.

> Overarching question
>
> In the context of the Tucson basin, what are the emerging water management challenges and what would be most adequate methodological tools to handle them?
>
> What are the major uncertainties for water management and what are the plausible future scenarios?

Table A4. 1 *– Research questions validation*

Question	***Stakeholders rate***	***SWAN rate***
Institutional and policy analysis		
What is the impact of the GW credits on the present and future dynamics of the water use budget in the Tucson Basin?	4	12
How are decisions regarding water resources management made in Tucson basin? How are these decisions legitimized? Who sits at the decision-making table? Who chooses them? How are the players selected & who do they represent?	3	10
How are management boundaries defined in Tucson basin? What factors determine selection of these boundaries (physical, administrative, political, etc)? What implications do these boundaries have on actors involved, allocation priorities, power structures and resource distribution?	3	4
How are land use and water resources planning integrated? What are the challenges?	2	3
How can run-off decrease trends affect the provision of CAP water to Tucson basin according to the existing priority allocation system?	0	7
How has the politics of water management evolved in Arizona?	0	4
How have economic and social forces shaped water demand during the development of the city of Tucson?	0	2
Hydrology and climate modeling		
Are there real trends of runoff decrease in the Colorado River? What are the reasons for these decreasing trends (climate	2	8

variability, land use changes, increasing groundwater abstractions, others …)?		
How will water resources in the Tucson basin be affected by changes in precipitation patterns caused by climate and land use changes?	2	4
How is natural recharge of the Tucson basin aquifer likely to be affected by changes in precipitation?	2	0
How is the quality of groundwater affected by CAP recharge? What are possible explanatory variables (type of agriculture, urban development, industry, petrol stations...) for variations in groundwater quality?	0	4
Socio-ecological modeling		
How is water demand affected by changes in the social structure (demography, economy, land use, energy price)? Are scenarios under the IV TAMA Management Plan capable of meeting safe yield by 2025?	2	9
In the context of agricultural water use, how much of the water is imported (from out of state) and how much is exported (as food products)? How does the price of energy affect agricultural water use?	1	7
What kinds of terrestrial ecosystems exist in the Tucson basin and how much aquifer recharge do they generate? How does land use change affect aquifer recharge?	1	2
What are the main factors explaining urban water demand? What are the reasons for observed decreases in demand?	0	5
How is water demand affected by changes in the social structure (demography, economy, land use, energy price)? Are scenarios under the IV TAMA Management Plan capable of meeting safe yield by 2025?	2	9

The most valued questions were those related to institutional and management settings, with an emphasis on the groundwater credit system. Other uncertainties like the shortages of water transfers in the CAP due to runoff decrease and the influence of changes in societal demand towards achieving safe yield were remarked in the other research areas.

Identification of Knowledge Gaps

After the initial prioritization exercise, participants were asked to spend 10 minutes thinking about key issues that had not been addressed in the initial proposed list of research questions and write them on a card. Below is a list of research questions proposed by participants grouped by category.

Hydrology and water availability

Stakeholders

- How will environmental water demands and ecosystems services be affected by changes in precipitation, climate and land use?

SWAN/Academia

- What are the space-time dynamics of water recharge/replenishment and removal from the TAMA system?
- How do these affect eco-biology of the system?
- How will groundwater withdrawals from shallow aquifer areas impact riparian habitats? Research on particular areas and sub-basins.

Socio-ecological modeling

Stakeholders

- What are the impacts of improved effluent water quality on natural systems?
- What emerging contaminants are found in CAP and effluents and which are their potential impacts?
- How to connect private well owners into water management? Decision making particularly in basin "edge" areas?
- How do environmental needs get factored into water resource decision making and management?

SWAN/Academia

- Future hydro-social impacts/dynamics of groundwater recharge credits and banking (especially future withdrawal)?

Institutional and policy analysis

Stakeholders

- How will changes in precipitation impact urban run-off? Potential impacts on growing green infrastructures investments?

- Where and how can green infrastructure compete with grey infrastructure in meeting needs of environment and people in the basin / larger regions? (for instance watershed restoration vs. new pipes and pumps)
- What format for regional water management are feasible in the Tucson basin, given the political state water law and private/public providers?
- What management choices can get us out of the trap of pitting human water demands against ecosystems water needs? Which are the win-win solutions?
- Which water use choices have the greatest potential to reduce trade-offs (conflicts) between human benefits (economic, growth etc) and natural systems functions.
- How does knowledge about natural systems values and vulnerabilities change water use choices at the level of individual users and policy makers?

SWAN/Academia

- Does rainwater harvesting create a "fixed demand" that has to be met using municipal water during drought (or even summer pre-monsoon)?
- Reflect on experience (successes and failures of water W/SP Public consultation). What is the appropriate outreach platform /techniques?

Other type of questions

Stakeholders

- What are resource needs and distribution scenarios for local food production?

SWAN/Academia

- How can this info/knowledge be used to better inform the public and affect the social and policy discourse?
- Could there be unintended consequences in adaptation efforts? (no regrets?)
- What are the gaps for water spatialised information? Since boundaries of water use change, you can't have spatial breakdown on urban demand, but only sectorial (like the water budget).
- Concerning the use of reclaimed water, is there an assessment of the effects on its use by the agricultural production in terms of food security and health?

Discussion

In the final part of the exercise participants were first asked to comment on the initial list of proposed research questions. They were then invited to present each of their new proposed questions, opening the floor to contributions and discussion with other participants. Below is a summary of the main issues that were raised during the discussion.

Water & Environment

- Environment and ecosystems water needs are not explicitly considered in the SWAN proposed list of research questions.
- Competition between increasing demand for the environment and from private well owners due to climate change, increases risks and vulnerability.
- Limited understanding of shallow groundwater dynamics is a significant limitation in the TAMA region. An updated well inventory, spatial information and groundwater modeling is required to better understand aquifer dynamics and the spatial distribution of effects from pumping and artificial recharge sites over shallow groundwater areas, and dependent ecosystems. This information could inform proposed spatial distribution of wells to minimize groundwater capture from environmentally valuable areas and thus maximize biodiversity conservation, in addition to achieving safe yield. .
- Over 70% of the Tucson basin region biodiversity concentrates in shallow groundwater areas. Mapping of key biodiversity hotspots linked to the levels of groundwater could help better target these areas for protection, concentrating pumping in regions where its impact is minimal to existing and potential riparian systems. Similar work such as the groundwater capture map in the San Pedro Basin and other initiatives in the Verde Basin were mentioned as precedent and illustrative examples.

Water & Food security, environmental justice

- Unequal access to shade and street runoff are key concerns in Tucson.
- Local food production. Inequalities in the access to water and food. Options for self-sufficient agriculture.
- Aesthetics versus ethics. Spatial classes segregation, functional relations of vegetation. Cultural gap between social classes, language.
- Higher dependency on ecosystem services of poor communities.

- Rainwater harvesting as local adaptation strategy. Rights? Conflict with prior appropriation rules? Additional demand to be managed? Options for upscaling?

Institutions & Management

- Most research questions proposed by SWAN are targeted to understanding the current situation while less attention is paid to potential future pathways, both in the immediate future and over the long term. Problems are already known by local stakeholders and expressed in different reports.

- What management choices can get us out of the trouble of confronting social and environmental demand? Where are the win-win choices? Where are they not? Which are the trade-offs?

- Potential pathways to face the fact that environment is not at the table in the Water Management Law. Inflexible institutions (rules to fix rules).

- Aquifer considered as a black box in the TAMA goals. Unacknowledged budget in relation to credits. GW replenishment district used to demonstrate 100 years availability but spatial disconnection between recharge and cuts. Cuts to the aquifers depending to the distance to the recharge area?

- Atomization of institutions, lack of coordination, pressure on discourses. 2008-2011 participatory process for Tuscon area infrastructure sustainability. Failures and successes? better cooperation between some administrations, the activist community is well informed.

- Motivation of institution to act? Institutions' driver is to meet customer needs. Leverage points? Water resource availability as increasing pressure to make institutional changes - information requirements on CAP supply.

Stakeholder Mapping

Table A4. 2 *- Relevant stakeholders in the Tucson basin related to water management issues*

Decision makers	Users and stakeholders affecting water system	Other stakeholders not affecting water system
Arizona Department of Water Resources	Agri-Business Council of Arizona	College of Agriculture and Life Sciences, University of Arizona
Bureau of Reclamation	Arizona Mining Reform Coalition	Department of Hydrology and Water Resources, University of Arizona
Central Arizona Project / CAGRD	Pascua Yaqui Tribe Land Department	The Nature Conservancy
City of Tucson	Tohono Tribe Water Resources Department	Save the Scenic Santa Ritas
Metro Water District	Business community	Hispanic Chamber of Commerce
Pima Association of Governments	Flowing wells irrigation district	Watershed Management Group
Pima County	Vail Water	Sonoran Institute
Tucson Active Management Area	Oro Valley (Philip Letto, John Kmiec)	Tucson Audubon Society
Tucson Water	City of Marana	Santa Cruz Pog (retirement community)
Southern Arizona Water Utilities Association	Herb	Friends of the Santa Cruz (Prescott VAnderbold)
	Fico-Green Valley	La Cienaga Creek Natural Preserve
	Chamber of Commerce (Ron Shorman)	

APPENDIX 5

Multi-criteria spatial analysis of sustainability in the Tucson AMA Water Accounting Areas.

In this appendix I develop a multi-criteria comparison of the three dimensions of sustainability for the different Water Accounting Areas (WAAs) with the aim of generating useful information that supports future sub-regional planning in the Tucson basin. The ADWR is on the process of disaggregating the water budget to the WAAs scale as proposed by the Safe Yield Task Force. A semi-distributed analysis of the water metabolism will then be possible. In the meantime, we downscale the overall sectorial budget for each Area to have an initial idea about how this is unfolding.

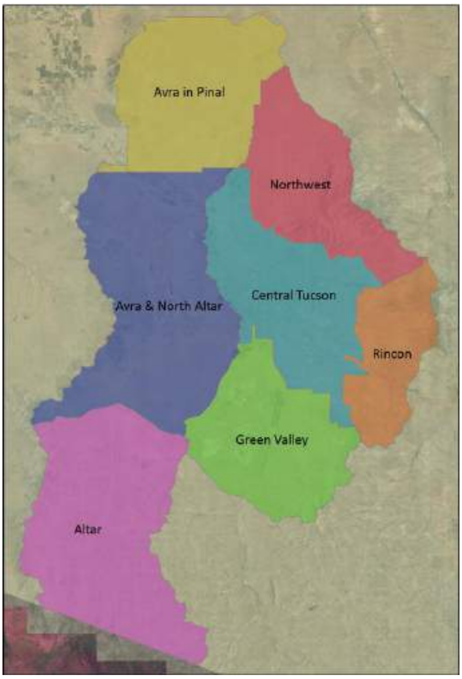


Figure A5. 1 *- Water Accounting Areas in the Tucson AMA*

Methodology

The set of indicators chosen for each analytical dimension are explained in Table A5.1. The indicators have been calculated for each WAA through geo-processing in ArcGIS 10.1 from the different information sources shown in Table 5.2 in Chapter 5. Both raw and processed data have been gathered in an ArcGIS personal geodatabase that can be opened and modified with Microsoft Access.

Table A5. 1 - Definition of sustainability indicators for Water Accounting Areas in the Tucson basin

Dimension	Indicator	Description	Unit
Water metabolism	Water sources	Water supply sources in each WAA	-
	Water use	Total water use and shares of each sector	AF
	CAGRD area	Part of each WAA covered by the CAGRD membership	%
	Exempt wells	Number of exempt wells in each area according to the Wells Registry 55 database downloaded from the AWRD in December 2014	Nº
Social	Population 2010	Population in each WAA according to the American Census 2010 (5 years average)	People
	% Population growth 2000-10	Difference of population in each WAA from 2000 to 2010 census	%
	% Urban area growth & main density type 01-11	Difference of area classified as urban in the USGS land cover map of 2011 regarding 2001	%
	Housing units	Total number of housing units in each WAA	Nº
	Median age	Average of median each for each WAA	Nº
Economic	% Employment	Number of people with employment out of total active working population.	%
	% Economic sectors	Percentage of total employment in each economic sector	%
	Income per capita 2010	Average income per capita of all Census Designated Places in each WAA	$/yr
Environmental	GW level range 2009	Maximum and minimum monitored water table levels in 2009	Feet
	Aquifer area with declining table 00-09	Part of the aquifer in each WAA where water table decreased from 2000 to 2009	%
	Max GW decline	Maximum groundwater decline in each WAA from 2000 to 2009	Feet
	Nº & surface SGWA (acres)	Number of Shallow Groundwater Areas in each WAA and surface within them	Acres
	SGWA over declining GW levels	Parts of Shallow Groundwater Areas that overlap aquifer levels decline from 2000 to 2009	%
	Water bodies & wetlands area growth	Increment of land cover classified as water bodies and wetlands in the USGS land cover map of 2011 regarding 2001	%

Water metabolism

Available sources have been assigned per area in relation to the water budget per sector and groundwater management information (recharge and recovery sites). The numeric code in the table is: 0=not used; 1= used; 2=to be confirmed.

The different water use sectors have been spatially disaggregated from the TAMA water budget through the following processes: The municipal service area was dissolved from the original shapefile and intersected with the WAAs layer. Proportional to overlaps with each WAA, municipal and industrial demands were downscaled per Service Area in each WAA, while discounting the area covered by mining operations. Mining sector demand was downscaled per area in each WAA and agricultural demand per area of IGFRs with actual Irrigation (attribute in the shapefile). Indian Nations demand was assigned to Avra&North where Tohono D'Oham Nation is located.

Exempt wells from the Registry 55 were intersected with the WAAs layer. Finally, the CAGRD service and new development areas were intersected with WAAs to have an idea of the surface in which groundwater can be withdrawn by their members.

Socio-economic

Data from census 2000 and 2010 was downloaded for all Census Designated Places (CDPs) in Arizona from America Fact Finder[50] as well as shapefiles of CDPs from Tiger geodatabase for the two dates. Each CDP was assigned to a WAA using a topological criterion of polygon centroid. The most unclear one was Marana which is between Central Tucson and Avra&North Altar. Following the topological rule it was assigned to the later. Socio-economic variables were calculated as averages per WAA with Summary Statistics over the table of attributes of CDPs on 2000 and 2010.

Urban growth and density was obtained from the difference between the USGS Land Cover maps 2011 and 2001. Raster maps were converted to shapefiles and intersected with WAAs. The evolution of the surface area of wetlands and water bodies has been also calculated from these layers.

Environmental

Groundwater levels have been interpolated through Inverse Distance Weight geoprocess (IDW) of the point layer with levels measured in 2009. The range of levels obtained from resulting raster was processed with the Statistics to Table ArcGIS geo-process.

[50] http://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t#

Groundwater level change was calculated interpolating of point layer attribute difference between years 2000-2009 and 2003-2013. Because for the second period there is a significant lower number of monitoring points, the analysis is based on the former while taking into account the later. The area of aquifer with declining water table levels was digitalized over the raster for the 2000-09 period.

The number and area of Shallow Groundwater Areas (SGWAs) within WAAs was obtained from the intersection of both layers. The percentage of SGWAs located over regions with declining GW levels was generated by intersecting the aquifer area with declining levels with the area of SGWA within each WAA.

Results

The results obtained are shown in Table A5.2, maximum values for each indicator are emphasized in bold.

***Table A5. 2 -** Sustainability indicators for the Water Accounting Areas*

		Avra Valley Pinal	Avra & North Altar	Altar	Northwest	Tucson central	Rincon	Green Valley
	ACRONYM	AVP	AVR	ALT	CAT	TUC	RIN	GRV
Water sources	CAP direct	2	1	0	0	0	0	2
	CAP in lieu	1	1	0	0	0	0	1
	CAP recovered	2	1	0	2	1	2	2
	Groundwater	1	1	1	1	1	1	1
	Reclaimed	0	1	0	0	1	0	1
	Reclaimed recovered	0	1	0	2	1	0	2
Water use	Total (AF)	4,415	122,970	4,798	45,895	214,621	22,316	64,897
	% M&I_Service	0	44	0	80	89	88	38
	% Mining	0	2	0	0	0	0	57
	% Agricultural	100	40	100	20	11	12	5
	% Indian	0	14	0	0	0	0	0
	Exempts wells	617	1,407	662	819	3,714	907	1,206
	Area of CAGRD (%)	0.01	0.5	0.0	0.15	0.94	0.45	0.11
Social	Population 2010	2,169	105,807	695	61,920	688,599	15,347	47,262
	Population growth (%)	2168	56	695	53	7	518	115
	Urban area growth & main density type (%)	11.7 High and medium	11.9 High	0.2 Low	35.2 High	13.8 High	100 Medium and high	32.0 High
	Housing units	786	43,069	492	31,332	308,469	5,798	28,190
	Median age	27	41	58	53	38	40	51

	ACRONYM	AVP	AVR	ALT	CAT	TUC	RIN	GRV
Economic	Employment rate (%)	NA	100	79	93	88	95	95
	% Agriculture & mining	NA	1.8	0.0	1.9	0.8	1.5	3.0
	% Manufacturing & trading	NA	28	0	25	24	28	31
	% Building & real state	NA	1.2	0	8	7	8	6
	% Services	NA	50	100	41	57	41	45
	% Government	NA	8	0	7	7	19	11
	Income per capita average 2010 ($/yr)	NA	19,523	23,507	34,086	26,168	35,094	29,778
Environmental	GW level range 2009 (feet)	53 - 452	85 - 736	4 - 460	19-687	11-655	23-608	9-453
	Aquifer area with declining table 00-09 (%)	4	21	61**	95	72	71	59
	Max GW decline (feet)	-4	-22	-**	-71	-44	-45	-46
	Nº & surface SGWA (acres)	0	1 - 368	5 – 3,853	7 – 1,029	9 – 10,709	8 – 3,087 (83,013)*	3 – 1,491 (94,635)*
	SGWA over declining GW levels (%)	-	0	-**	47	63	25	100
	Water bodies & wetlands area growth (%)	2	79	90	6	9	11	248

* Whole SGWA system ** No representative data

Water metabolism

ALT and AVP are the only WAAs with water demand exclusively devoted to agriculture and a minor number of exempt wells. On the other hand TUC and AVR show the highest water demands and exempts wells. AVR stands out for containing all types of water uses and sources: the Tohono O'Odham Nation is located there, and the Area contains the greatest irrigation surface, an important urban area in Marana and two mines. It also contains the major CAP-USF as well as GSF and reclaimed water USFs. CAT, TUC and RIN demand is mostly urban depending on municipal providers, exempt wells or CAGRD. TUC has three reclaimed water USFs and uses direct reclaimed water, as well as imported recovered CAP water from AVR. GRV contains 3 recharge sites, one for CAP right south of Tucson city and 2 for effluent in the south disconnected from CAP. The greatest mines with groundwater withdrawal permits are located here as well as a significant number of exempt wells.

Regarding the area covered by the CAGRD (including service and new subdivisions), TUC is mostly covered in all its extension and AVR and RIN in half of it. CAT and GRV have a lower cover but the largest shares of new subdivisions (2% each).

Socioeconomic

Population and urban areas have grown in all WAAs, and most of them are also densifying. ALT and AVP had their first Census Designated Places recognized in 2010 and thus their population was accounted in this census for the first time.

ALT is a particular case of low density urban development with the eldest population in average and lowest employment rate. It is specialized on the services sector related to ecotourism. On the other hand, AVR, RIN and GRV show the highest employment rates, maintaining a significant rate of agriculture and mining employment and an important manufacturing sector.

The Santa Cruz sub-basin is the one that has experienced a greater development in the last ten years, mostly in RIN, CAT and GRV. RIN and CAT show very similar patterns: peak income per capita of all WAAs, a relatively lower importance of the services sector and the highest share of employment on real state and building activities. A remarkable difference is the relevance of the government sector in the RIN WAA with up to 19% of the employment. The GRV area also shows average income per capita higher than in the other Areas, highlighting the relevance of the mining sector.

TUC is the WAA that grew in the slowest pace in the last decade, essentially because it is already mostly urbanized. Expansion areas move up the hills in Tanque Verde, Catalina Foothills and Casas Adobes. These three CDPs raise the average income per capita since Catalina Foothills and Tanque Verde have the highgest of all CDPs (>45,000 $) while Tucson city has the lowest of all (20,300 $). They also have elder population and higher employment rates than Tucson.

Environmental impacts

Groundwater levels are increasing in most of the AVR and AVP area north of the recharge sites. Interestingly, AVR is still the area where the water table is the deepest of all, indicating that most groundwater overexploitation occurred here. This is likely related to the fact that most historical agricultural activity has taken place in this area. South of recharge sites in AVR, levels were still dropping in 2009. ALT data shows a mellow decline of 6.9 feet/year on average for its central part. Nevertheless, land cover maps show that an important increase in herbaceous wetlands has been experienced along the central riparian area from 2001 to 2011. This WAA counts with only 4 monitoring wells, and therefore interpolation results might not be very representative. More monitoring wells would be advisable. CAT, TUC and RIN are located over the wide Upper Santa Cruz aquifer plateau and show similar groundwater depths. They also have the highest portion of the aquifer with dropping levels concentrated around three hotspots: mines and new developments of Green Valley CDP in GRV, new developments of Rincon Valley CDP in RIN and Oro Valley and Casas Adobes CDPs in CAT.

Six of the seven WAAs have Shallow Groundwater Areas (SGWA), most of them located around the mountain ranges of Catalina and Rincon mountains (NEW, TUC and RIN). RIN and GRV have small parts of the largest SGWA-dependent systems that continue outside the TAMA. The interpolation of groundwater monitoring points shows that all WAAs of the Tucson aquifer have parts of the SGWA over declining groundwater levels, albeit these declines are low (~0-12 feet on average for the period 2000-2009) in the Tanque Verde-TUC area and moderate in Northwest CAT (~12-24 feet) and RIN (~24-37 feet). The updated data for 2003-2013 level changes shows the continuous recovery of Tucson central levels and a greater and more extended decline in the GRV hotspot up to 72 feet. An enormous increment of water bodies area in the GRV is observed due to the huge pools inside the mines.

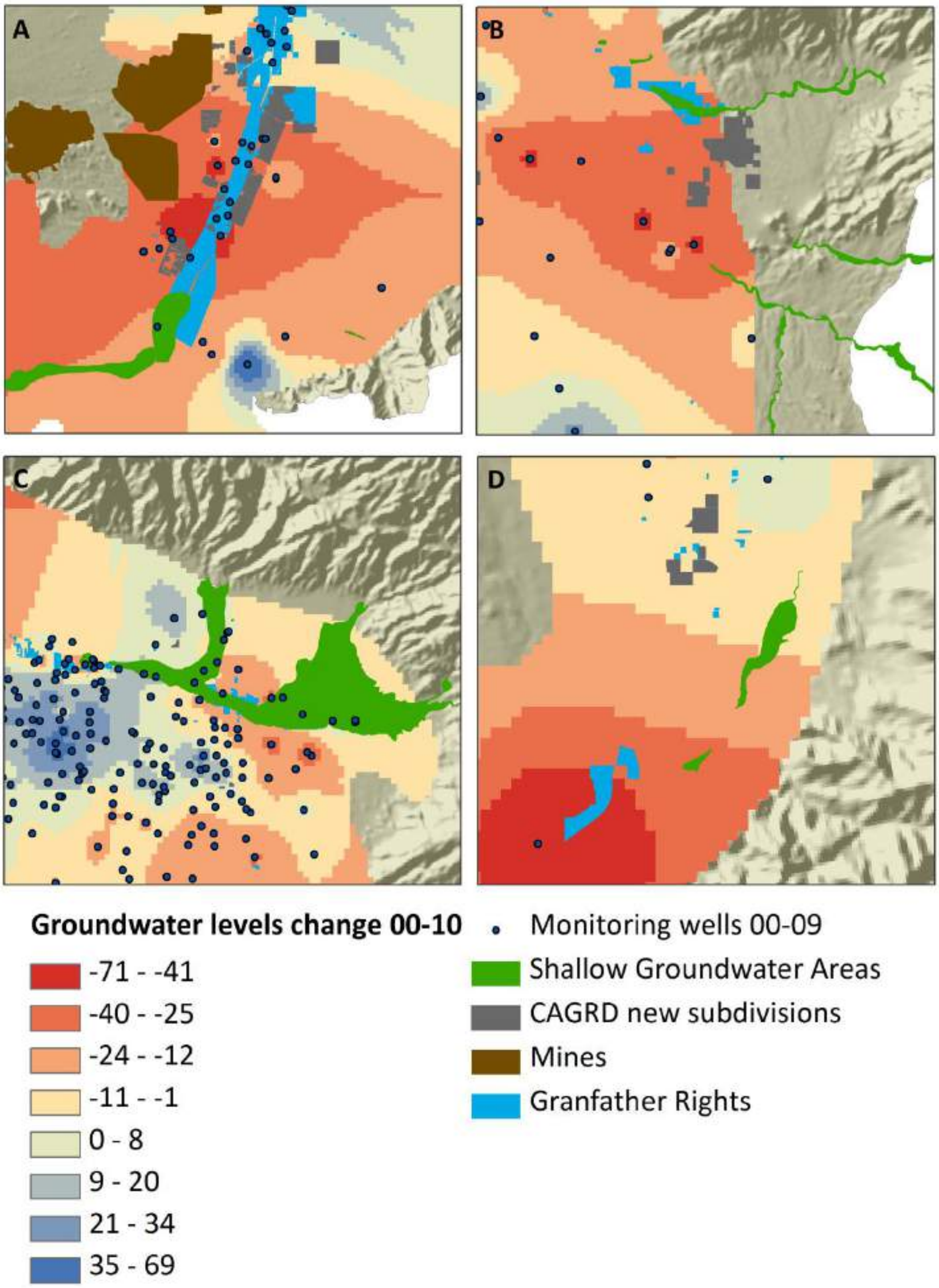


Figure A5. 2 *- Detailed maps of SGWA A – Santa Cruz – Sopori Wash in GRV; B – Cienaga and Rincon creeks in RIN; C – Tanque verde in TUC; D – Sutherland Wash in CAT*

APPENDIX 6

Table A6. 1 *- Comparative of WFD and GMA*

	Water Framework Directive	Groundwater Management Act
Year of approval	2000	1980
Planning horizon	Six year planning cycles (2015-2021-2027)	2025
Spatial scope	European Union Member States	State of Arizona
Sustainability objective	Achieve good status (chemical and ecological) for surface waters and chemical and quantitative for groundwater by 2015	Achieve specific groundwater management goals for each Active Management Area (Safe yield for Phoenix, Pinal and Tucson AMA, and maintain agricultural economy for Pinal AMA)
Governance regime	Centralized in River Basin Authorities in cooperation with sectoral policy administrations (agricultural, industrial, land use, etc.)	Decentralized in water providers and groundwater users
Planning mechanism	Management plans in 6 years cycles for each river basin lead by River Basin Authorities	Managements plans for each AMA in 10 year cycles lead by the ADWR
Management extent and delimitation criteria	River basins based on surface hydrological criteria. Environmental objectives are assigned for each surface and groundwater body	Active Management Areas in highly populated areas based on groundwater hydrological criteria

APPENDIX 7. Curriculum Vitae (10/2015)

Department of Human Geography. University of Seville.
Adress: Calle Maria de Padilla s/n 41004 Sevilla
Phone: +34954559526 Cell: +34627246343
E-mail: vcabello@us.es / vcabellov@gmail.com
Twitter: @vcabellov @WaterP2P
Blog: www.aquabits.net
Research Gate: https://www.researchgate.net/profile/Violeta_Cabello
Linkedin: es.linkedin.com/in/VioletaCabelloVillarejo

RESEARCH INTERESTS

Multi-scale connections between water governance, socioeconomic and ecohydrological processes; modeling of complex social-ecological systems; land-water-energy-food nexus; inter and trans-disciplinary practices in sustainability research; citizen science; open data and ICT's for natural resources management.

ACADEMIC EDUCATION

2010-2016: Doctorate. Geography.

Department of Human Geography. University of Seville. Spain

2008: Msc. Environmental Hydrology *(high distinction)*

Andalusia Center for the Environment. University of Granada. Spain

2006: Msc. Applied Ecology.

Department of Environmental Sciences. Halmstad University. Sweden

2007: Bsc. (5 year program). Environmental Sciences.

University of Malaga. Spain

RESEARCH EXPERIENCE

2015 - 2016: Project researcher.

Sustainable Water Action-SWAN- EU FP7 INCOLAB research project. University of Seville.

Mar - May 2014: Visiting scholar

Department of Water Resources Planning. UNESCO-Institute for Water Education.

Mar - July 2013: Visiting scholar

iGLOBES – Interdisciplinary and Global Environmental Studies Center. University of Arizona (USA).

Nov 2014 - Mar 2015: Visiting scholar.

iGLOBES – Interdisciplinary and Global Environmental Studies Center. University of Arizona (USA).

REASM – Regional Economics and Spatial Modeling laboratory. University of Arizona (USA).

Sep 10 - Jun 11: Visiting scholar.

Institute of Environmental Sciences and Technology. University of Barcelona (Spain).

2010 - 2014: Doctoral researcher

Education Program for University Profesors (FPU). Spanish Ministry of Education.

2009 - 2010: Project manager.

ALGATEC FP7 project. BIOAZUL S. L.

Mar - Jun 2006: Visiting student.

University of Kalyani (India). International Center for Ecological Engineering.

PUBLICATIONS

Peer-reviewed journals

Cabello, V. Willaarts, B., Aguilar, M., and del Moral, L. River basins as social-ecological systems: Linking levels of societal and ecosystem metabolism of water in a semiarid watershed. Ecology and Society 20(3):20. http://www.ecologyandsociety.org/vol20/iss3/art20/

Pedregal B., **Cabello V.,** Hernandez-Mora N., Limones N. and del Moral, L. 2015. Information and knowledge for water governance in the networked society. Water Alternatives 8(2):1-19. http://www.water-alternatives.org/index.php/alldoc/articles/vol8/v8issue1/278-a8-2-1/file

Hernandez-Mora N., **Cabello V**., di Stefano, L. and del Moral, L. Networked water citizen organizations in Spain: Potential for transformation of existing power structures for water management. Water Alternatives 8(2): 99-124. http://www.water-alternatives.org/index.php/alldoc/articles/vol8/v8issue2/283-a8-2-6/file

Cabello Villarejo, V., Madrid Lopez, C. 2014. Water use in arid rural systems and the integration of water and agricultural policies in Europe: the case of Andarax river basin. *Environment, Development and Sustainability* 16(4):957–975.

Ravera F., Gamboa G., Scheidel A., Dell'Angelo J., Serrano T., Mingorría S., **Cabello V.**, Ariza P., Arizpe N. 2014. Pathways of rural change: An integrated assessment of the metabolic patterns of emerging ruralities. *Environment, Development and Sustainability* 16(4):1-10

Madrid C., **Cabello V.,** Giampietro M. 2013. Water-Use Sustainability in Socio-Ecological Systems: A Multiscale Integrated Approach. BioScience. 63(1):14-24.

Sova Patra Das T., Avila, C., **Cabello V**., Castillo F., Sarkar D. Lahiri S., Jana B. 2012. Cadmium tolerance and antibiotic resistance in Escherichia coli isolated from waste stabilization ponds. Indian journal of experimental biology 50(4):300-7.

Book chapters

Cabello V., Hernandez-Mora N., Serrat-Capdevila A., and del Moral L. 2016. Water use and sustainability in the Tucson basin: implications of a spatially neutral approach to groundwater management. In Gupta H., Gupta M., Poupeau F., Serrat-Capdevila A., (Eds)Water in the Desert. A transatlantic transdisciplinary dialogue.

Working papers

Serrat-Capdevilla A., **Cabello-Villarejo, V.,** Boyanova K., Poupeau F., Rodriguez, D., Salmoral, G., Segura, S., Yang, Z. 2014. Analyzing new challenges for water management: a review of existing conceptual frameworks and outlines for a trans-disciplinary approach. Deliverable of the Sustainable Water Action- SWAN- project. EU Incolab FP7.
http://swanproject.arizona.edu/sites/default/files/Deliverable_5_Supplement1_web.pdf

Madrid, C. and C**abello, V.,** 2011. Re-opening the black box in Societal Metabolism: the application of MuSIASEM to water. ICTA Working Paper. http://www.recercat.cat//handle/2072/172087

Master thesis

Cabello Villarejo, V. 2008. Semi-distributed model of nutrients transport in the Guadalfeo river (South-East Spain). ISBN 978-84-692-4197-4

RESEARCH PROJECTS

2012-2016: Sustainable Water Action-SWAN- Building research links between EU and USA. INCOLAB VII EU Framework Program

2013-2016: Citrus-ProPlanet. Coordinated by Global 2000, funded by REWE. Participatory workshops coordinator.

2009-2012: Participatory planning of water management alternatives in the Andarax river basin (ALTAGUAX). EU ALERT Program.

2011-2013: Participatory Agenda 21 in Órgiva (Spain). Federación Andaluza de Ciencias Ambientales.

2011: Trans-boundary Water Basin Management: Jordan River (TRANSBASIN). Marie-Curie VII EU Framework Program.

2009-2010: Biotechnological recycling of olive mill rinse water by micro-algae (ALGATEC). Research for SMEs VII EU Framework Program.

RELEVANT INTERNATIONAL CONFERENCES

Jun 2014: International Conference on Data, Information and Knowledge for Water Governance in the Networked Society. Seville. Co-organizer.
http://grupo.us.es/giest/es/node/906

Dec 2013: IX Iberian Conference on Water Planning and Management. Lisbon.

Multiscale analysis of water metabolism to evaluate water planning scenarios. Communication

Transdisciplinary approach for sustainable action on water issues. Poster

Sep 2013: IV EUGEO Congress: Europe, what's next? Changing geographies and geographies of change. Rome.

The integration of water and agricultural policies: a societal metabolism approach. Communication

Nov 2012. EGU Leonardo Topical Conference Series on the hydrological cycle. Hydrology and Society: Connections between Hydrology and Population dynamics, Policy making and Power generation. Turin.

Analyzing water metabolism in Socio-Ecological Systems: A Multi-Scale Integrated Approach. Communication

ESEE 2011: Advancing ecological economics: theory and practice. Istanbul, Turkey.

Multi Scale Integrated assessment of Socio-ecological metabolism of water. Communication

RELEVANT TALKS AND SEMINARS

Apr 2015: *Water use and sustainability in the Tucson basin: implications of a spatially neutral approach to groundwater management.* SWAN 4th Annual meeting. Sofia, Bulgaria.

March 2015: *#WaterP2P: An introduction to the citizen science and open knowledge movements. What about water?* SWAN Central Seminar. University of Arizona, Tucson, USA.

Nov 2015: *Multi-scale analysis of Socio-Ecological systems metabolism: application to the Tucson basin.* Kick-off meeting of the Observatory of Man and the Environment OHMI- project. University of Arizona, Tucson, USA.

May 2013: *Water Metabolism in Socio-Ecological Systems: A multi-scale integrated approach*. The Vincent and Elinor Ostrom Workshop in Political Theory and Policy Analysis. Indiana University, Bloomington, USA.

May 2012: *MuSIASEM for Water*. Workshop on Water Metabolism. Universidad Pablo de Olavide, Seville, Spain.

TEACHING

University of Seville. Spain.

2012- 2015: Arc-GIS: Vector data. Bsc. History and Geography.

Jan 2014: Course on participatory methods for teaching. Institute of Education.

Feb 2014: Course on participatory methods for research. Institute of Education.

FACILITATION OF PARTICIPATORY AND RESEARCH WORKSHOPS

Mar 2014: Citrus-Proplanet project*. Water conservation at the farm scale.* Valencia (Spain).

SWAN project

Nov 2014: *Let's tell the story of the Tucson basin case-study.* 5th progress meeting. Tucson (USA).

Oct 2013: *I participatory workshops on water research management links in the Tucson basin.* Tucson (USA).

Jan 2013: *New paradigms of water management and risks: data and information.* Seville (Spain).

ALTAGUAX project

2012: V workshop*. Decision Support System presentation and assessment.* Almeria (Spain)

COMPLEMENTARY EDUCATION

IIFACe Institute for facilitation and change in Spain

2015-2016: *First course on groups' facilitation.*

2015: *Introduction to groups' facilitation*.

Coursera

2014: *Data analysis with R.*

2013: *Introduction to R programming.*

University of Seville

2014: *Spatial databases: PosGis.*

2013: *Geographic Information Systems and Geodatabases II.*

2012: *Qua Geographic Information Systems and Geodatabases I.*

2012: *Qualitative research methods.*

LIPHE4 Scientific Society.

2012: 7th Summer School: *Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM): An innovative approach to energy analysis.* Barcelona (Spain).

XV International Erasmus Program Seminar on Geography of Water.

2012: *Sustainable Water Policies for Europe*. Munich (Germany).

SCARCE-CONSOLIDER Project.

2011: *Economics for water ecosystem services management*. Seville (Spain).

UNIA International University of Andalusia

2011: *Image code: data visualization with Processing*.

2011: *Digital tools for participatory mapping*.

2011: *Complex Thought and Sciences for Complexity.*

LANGUAGES

Spanish: Native speaker English: Proficient user Portuguese: Basic user

Diseño e ilustraciones por Sabina Cabello Villarejo http://www.sabinacabello.com/

UNIVERSIDAD DE SEVILLA