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Knowledge for action

Contributions of hydro-economic models to water management in France

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Economic analysis plays an increasingly important role in managing water resources and aquatic environments. For example, it can assist water managers in determining the economic value produced by various water uses in a river basin. It can also contribute to identifying the most cost-effective programmes of measures in view of reaching good status of water bodies. Unfortunately, economic studies are often carried out in parallel to hydrological studies, i.e. the hydrological functioning of the basin and the dependant socio-economic processes are not analysed in an integrated manner. As a result of this partitioned approach, numerous interactions are not included in the models, e.g. the relations between activities located upstream in the river basin on the one hand, and water availability and quality for other uses downstream on the other.

Hydro-economic models are particularly useful in breaking through the partitions because they can assess the impact of different measures and management policies on water uses, resources, aquatic environments and the overall economic effectiveness of hydrological systems. These models are already used in the United States, Spain and the U.K. to explore options and assist in decision-making and management of water policies. In view of WFD (Water framework directive) implementation and the set objectives, Onema and BRGM decided to present the experience acquired abroad to French water managers. Using concrete examples, this document shows how hydro-economic models can assist in dealing with three major problems confronting the managers of water resources.

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I- What is a hydro-economic model?

A hydro-economic model (HEM) combines in a single tool a wide range of equations representing, on the one hand, the biophysical processes governing the functioning of aquatic environments and, on the other, the economic processes by which humans make use of aquatic environments (see Figure 1). It attempts to mirror the complexity of the interactions between human activities and water resources in a single analytical framework.

HEMs are designed to help managers in optimising water management based on essentially economic criteria. Three main assumptions underlie the models:

- **use of water has economic value** (see Box 1). Water resources are used by activities producing economic value, i.e. wealth or benefits for users;
- **water management incurs implementation costs.** To reach their objectives, managers must set up measures that may incur high costs (investment, operation, maintenance, etc.);
- **water management impacts water use.** The measures implemented by managers can modify the hydrological functioning of a basin and/or the dependant human activities. They can impact water usage in the local area where the measures take place and in other areas (modifications upstream can affect usage downstream), and they can affect other resources (a measure concerning groundwater can impact use of surface water).

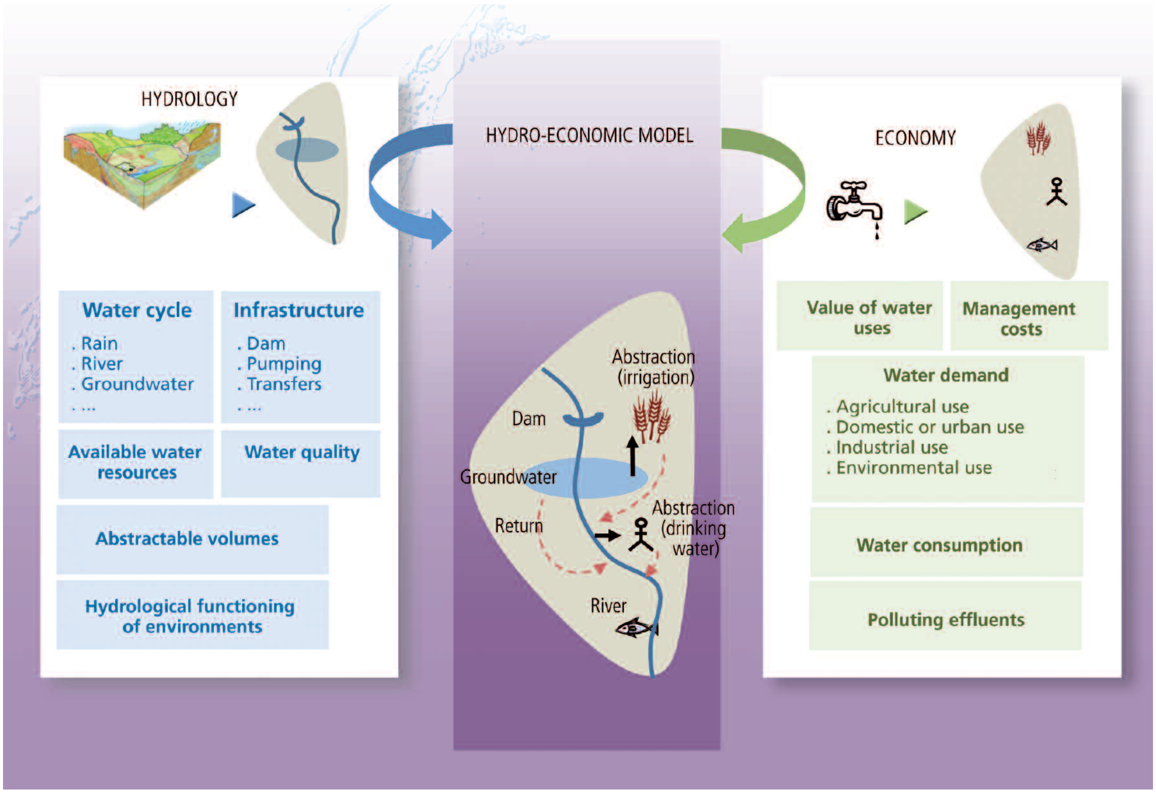

Figure 1. *Diagram showing the hydrological and economic components integrated in a hydro-economic model.*

The economic value of water use

The use of water consists of drawing water to satisfy a need. Water serves for multiple human needs (drinking water, irrigation, hydroelectric generation, fishing, etc.). Use of water by humans is thus a means to improve their welfare. In economics, an improvement in welfare is called a benefit.

To quantify a benefit in monetary terms, the economic value of the water use must be calculated. The result is expressed in euros. The economic value varies according to the use (household, agricultural, environmental, etc.).

For example, in the agricultural sector, water is an intermediate good, i.e. a good used to produce another good (wheat, maize, etc.). But in the drinking-water sector, water is a final good, i.e. a good intended for consumption by humans.

Without going into the details of how the economic value of water is determined for each use[1], it has been established that:

- the economic value of water used for agriculture depends on the type of production for which it is used. In France, the value per cubic metre is only a few euro cents for cereal crops, but rises to over one euro for vegetable farming;
- the economic value of drinking water depends on the quality of the water. The average value in France is a few euros per cubic metre.

Water is used for an array of purposes. Its value varies from one river basin to another and among water users in a given basin. It also varies depending on the period (summer or winter, the year, etc.) and on the quality of the resource (good or poor status, etc.).

To enhance the management of water resources from an economic perspective, a water manager must be capable of quantifying and comparing the value of water for different uses. It is then possible to assess the economic impact of measures taken on the hydrosystem.

Box 1

The shared characteristics of hydro-economic models

HEMs are **integrated models** that are capable of reproducing the **interaction and feedback** between the hydrological and economic components of hydrosystems[2] (effects of human activities on aquatic environments, effects of a reduction in the available quantities of water on the economic value of water uses, etc.).

They are **computer tools** that represent, in simplified form, the dynamic functioning of systems made up of water resources, users, infrastructure and aquatic environments.

HEMs are **exploratory, decision-support tools** used to provide stakeholders with information on a wide range of management strategies, notably the technical, physical, environmental and socio-economic impacts of different sets of measures and water-management policies that could be implemented. In this sense, the models can be used to clarify debates and inform decision-makers on the economic issues involved when selecting management policies.

1. For more information on the economic value of water uses, see Salvetti, M., 2013. Economic analysis for management of water and aquatic environments. Onema. *Knowledge for action* series. 172 pages.
2. A system comprising water and aquatic environments in a specific geographic sector, often a river basin.

They can take **environmental preservation** into account in the management rules for a hydro-economic system (e.g. minimum environmental flows) and deal **simultaneously with the problems concerning the quantity and quality of water resources.**

They are also capable of detecting conflicts concerning water usage and, via scenarios, providing information on the potential trade-offs between the different water-management objectives (e.g. satisfying one use to the detriment of another, reducing management costs or risks, meeting environmental objectives, etc.).

The components of a hydro-economic model

An HEM is made up of the elements listed below.

- **A representation of the studied hydrosystem** shown as a network made up of hydrological sections (river reaches, canals, pipes) linked together by nodes representing storage points or delivery points to consumers (reservoirs, dams, abstractions, groundwater bodies, etc.).

- **A representation of the studied economic system** presenting in detail the supply and demand for water of the various uses (drinking water, agriculture, industry), the effluents and the corresponding operating costs.

- **A database** containing the information on the components of the modelled systems:
  - the "hydrological" component (precipitation, runoff, water quality, river discharges, groundwater levels);
  - the "infrastructure" component (storage and transfer capacities, management rules, operating costs);
  - the "water use" component (history of consumption and effluents, projections of future trends).

- **A framework of equations** describing the functioning of the hydrological and economic systems, and their interactions, for example:
  - the relevant hydrological processes (hydrological flows, rain-discharge and groundwater-river relations, trends in water quality, dilution or natural attenuation of pollutants);
  - the storage and transfer functions of the infrastructure (canals, dams, pipes) and, in some cases, the water-treatment functions;
  - the economic processes, the benefits and costs arising from various water uses, the trends resulting from changes in parameters such as the available quantities of water and water prices.

- **A set of rules,** concerning notably the environment (minimum environmental flows, minimum water quality), technical aspects (maximum capacity of infrastructure) and regulations (priorities accorded to certain uses, maximum permissible level of risk for supply to certain uses, authorisations for abstractions or releases).

- **An interface** enabling the user to run the model in either simulation mode (to explore the impact of scenarios, measures and water-management policies) or optimisation mode (to identify the most cost-effective programmes of measures or to devise water-resource allocation schemes that maximise the economic benefits for the area as a whole).

Today in France, hydrosystem managers base their decisions on an approach to water demand consisting of projections for population growth, abstraction licenses, economic issues and political priorities for local development. Hydro-economic models would put them in a position to base their decisions on a more integrated approach to water demand, focussing on the economic value of water uses, and thus introduce among the decision criteria the economic benefits arising from water usage in their area.

The following sections present three concrete examples of situations for which HEMs can provide useful information and where their implementation could prove beneficial in the French context.

II- Hydro-economic models and selection of a programme of measures

Which programme of measures is the most cost-effective in meeting WFD objectives?

In Europe, the WFD (Water framework directive) requires that managers of river basins set up programmes of measures to ensure the "good ecological status of water bodies" in the most cost-effective manner. To that end, managers assess both the impact and the costs of the programmes of measures. It may be necessary to assess the benefits produced by the programmes in order to demonstrate that the costs of reaching good status for a water body are disproportionate, thus justifying an extended deadline or the setting of less rigorous requirements for the water body.

Theoretically, managers attempt to design a programme of measures capable of meeting both present and future needs, while reconciling environmental objectives (restoring or maintaining good status) on the one hand and compliance with the economic and technical management rules applying to the hydro-economic system on the other.

Use of an HEM can be of assistance in identifying the set of measures best suited to reaching the objectives at the lowest cost, i.e. the most cost-effective solution. The model can also be used to optimise the scheduling of the measures over time, again in view of reducing the total cost of the programmes of measures.

Example of use by U.K. drinking-water companies

■ Context

In the United Kingdom, water companies are overseen by an economic regulator (Ofwat, the Water services regulation authority). Ofwat ensures that water tariffs are sufficient to fund all the costs involved in supplying drinking water, but also that the investments decided by private companies are reasonable.

The private companies are required every five years to submit to Ofwat and the Environment agency a business and environmental plan detailing their investment programmes for water management over the next 25 years. On the basis of the submitted plan, Ofwat sets the maximum amount that the companies may bill to their customers in view of financing the investments. This five-year planning process forces the companies to regularly adjust their strategies taking into account the projected trends in demand and the available quantities of water. Shortly after the year 2000, the water companies started to use a joint analysis framework in justifying their investment programmes. Developed by the UK Water Industry Research Organisation (UKWIR), the framework stipulates the method that water companies must use to formulate their investment plans every five years.

One of the main steps in the method consists of modelling the hydrology and the economy of river basins in view of selecting the measures best suited to cost-effective provision of water, while ensuring compliance with all environmental-protection rules. The use of the joint analysis framework contributed significantly to the development and use of HEMs by water companies in the United Kingdom. An optimisation model was used in the south-eastern section of England, an area roughly the size of French region Lorraine (21 000 square kilometres) where tensions concerning water use have increased due to population growth and the risk of droughts. Six private companies supply 17.6 million people in the region with water. Estimates for water demand by 2039 produced a figure of 2.3 billion cubic metres per year (Gm^3/year), which corresponds to an average annual shortage of 312 million cubic metres per year (Mm^3/year), with significant differences between parts of the region, some having excess supply and others deficits. Consequently, the water companies formed an alliance, called the Water Resources in the South East Group (WRSE Group), to study together the means of achieving the most cost-effective allocation scheme of resources spanning the entire region.

■ The hydro-economic model

The purpose of the HEM developed by the WRSE Group is to devise the most cost-effective programme of measures capable of meeting present and future demand for water as well as the environmental objectives set by the WFD. The period covered by the model corresponds to the Ofwat requirement, i.e. 25 years (2015 to 2039) for the current plan to be renewed in five years. The hydrosystem and the impact of climate change are simulated using a hydrological model capable of estimating the available quantities of each type of water resource for each year (see Figure 2).

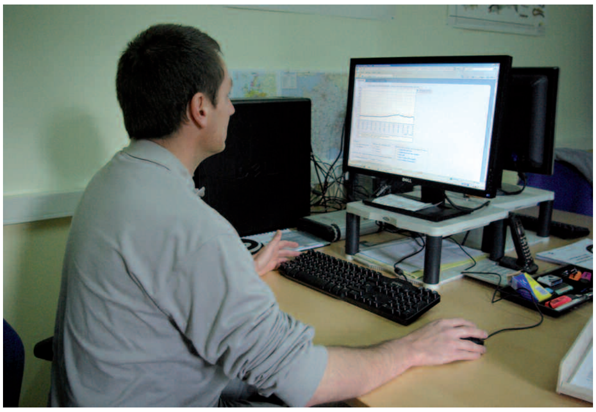

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Figure 2. *In designing a hydro-economic model, it is necessary to collect data on the hydrological and economic components in the hydrosystem.*

The resulting data are subsequently fed into the HEM of the WRSE Group. The elements of hydraulic infrastructure are presented in the nodes of the model, including groundwater and river abstractions, systems for the reuse of wastewater, desalination plants, water-treatment plants and storage reservoirs. Demand for water is calculated for each type of use, on the basis of consumption data supplied by the water companies. To take the uncertainty concerning future trends in the areas into account in balancing supply and demand, the HEM uses four different scenarios for demand trends over 25 years, where each is assigned a probability of occurrence.

This regional model was used by the water companies to identify the most cost-effective programmes of measures satisfying agricultural and urban demand in South-East England, each year from 2015 to 2039. The measures to reduce the projected shortages deal with limiting demand (511 measures), drawing on new resources (283 measures) and water transfers (267 measures). Various scheduling scenarios for the implementation of certain measures are also taken into account, e.g. construction of a dam on the Thames River is assumed to take place in two distinct steps.

The HEM indicates:

■ the **most cost-effective combination of measures** required on the regional scale to eliminate the projected shortages. This means that the programme of measures is optimised with respect to the costs incurred;

■ **the best schedule for implementation and use of the various management measures** planned over the set period. This means that implementation of the measures is optimised over time.

The model thus puts the water companies in a position to look at cost-effective options from outside their own territory (water transfers from other regions). It also improved the efficiency[3] of measures thanks to economies of scale[4] made possible by the wider area considered in the regional analysis.

Following this work, ten programmes were proposed to managers, differing according to the types of measures and the various demand and climate scenarios (see Figure 3). Their total discounted cost, i.e. the sum of the implementation costs for each programme of measures over the duration of the programme, discounted to their current value ($€_{2013}$), varied between 1 and 2.1 billion euros, depending on the selected assumptions and measures (see Figure 3).

For example, between 2000 and 2005, this type of model justified four major water transfers in the region, representing a total of over 10 million cubic metres of water per year.

3. The economic efficiency of a measure, an investment or a policy is the ratio between the benefits produced and the cost of implementation. Economic efficiency increases with the ratio.

4. An economy of scale is a drop in the unit cost of a product achieved through an increase in the quantities produced. One of the main causes of economies of scale is fixed costs (costs incurred whatever the quantities produced). In this example, the economy of scale arises from the fact that an increase in the volume of water transiting a facility reduces the unit transfer cost of each cubic metre of water.

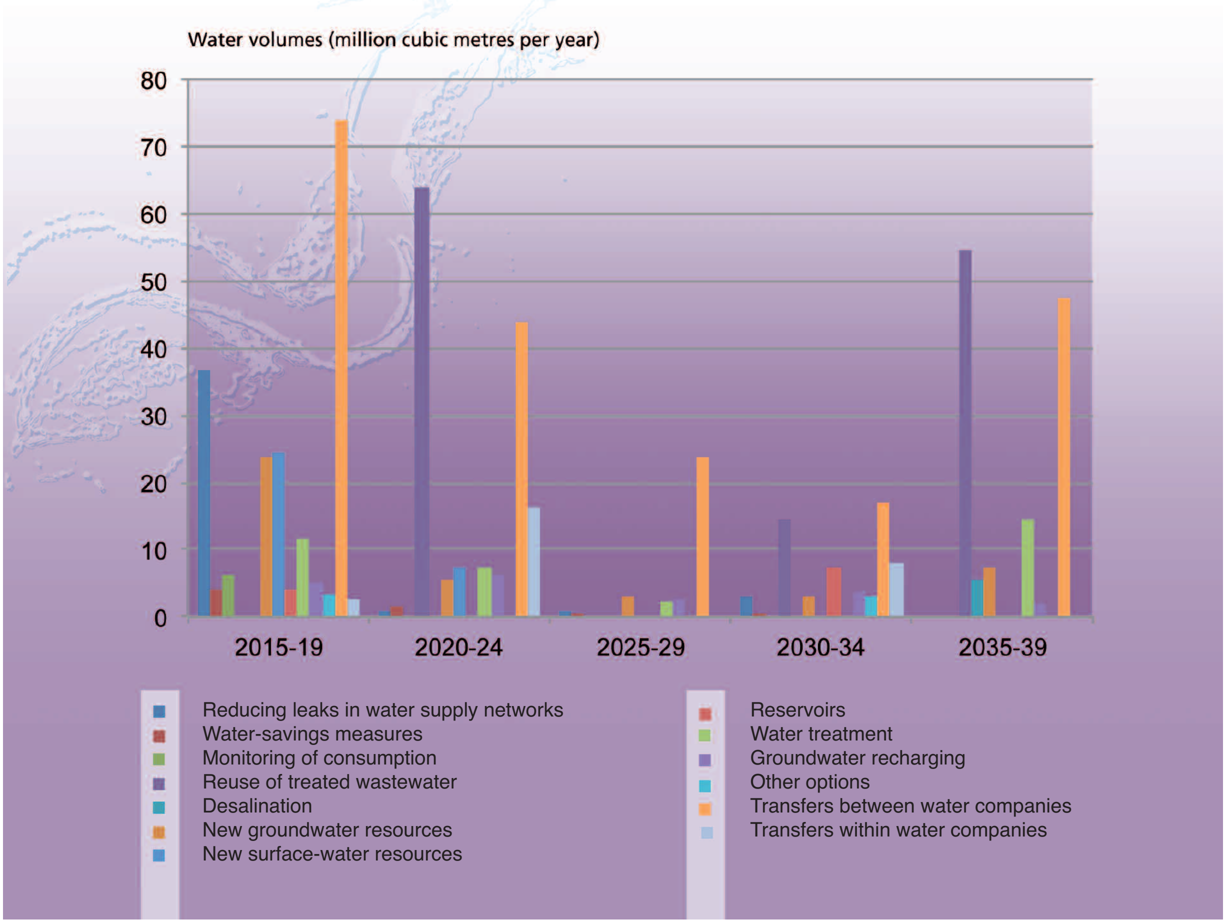

Figure 3. *Example of the results produced by the hydro-economic model developed in SE England. Water volumes calculated for measures to reduce a shortage in a scenario taking into account critical hydrological conditions between 2015 and 2039. Source: adapted from WRSE Group (2013), Progress towards a shared water-resources strategy in the South-East of England.*

Over the 2015-2019 period, efforts deal primarily with demand-side measures (reduction in leaks, water saving, etc.). Work is also undertaken on mobilising new groundwater and surface-water resources and on transfers between water companies. Subsequently, reuse of treated wastewater and transfers between water companies are the main measures, notably during the periods 2020-2024 and 2035-2039. For the period 2015-2039 as a whole, new water supplies for the region are primarily the result of water transfers. Efforts to limit demand are, generally speaking, limited. However, given that they can be implemented quickly, they are systematically used during the initial years in order to compensate short-term deficits.

Outlook for France

In France, HEMs could be used to complement or replace cost-effectiveness analysis in order to provide the members of local water commissions with food for thought during the formulation of programmes of measures for sub-basin management plans (SBMP) targeting either qualitative or quantitative water management. For example, in the framework of the research leading to this report, an HEM targeting the definition of a least-cost programme of measures for the Orb basin (Hérault department) was developed jointly by BRGM and the Technical university of Valencia in Spain (see Box 2). Similar to the U.K., this type of model could be useful in better managing water prices and the investments undertaken by water services in France. Models similar to the English model could also be used in France to optimise the cost of programmes of measures targeting improvements in the quality of aquatic environments. This type of model has already been developed for the Jucar basin in Spain (see Box 3).

Model for least-cost optimisation of a programme of measures for quantitative management in the Orb basin (Hérault department)

Located on the Mediterranean coast, the Orb basin (1 580 square kilometres, 64 towns) is directly confronted with major local and regional issues concerning water management. To date, the reservoir behind the Monts d'Orb dam (30 million cubic metres, see Figure 4) has guaranteed the supply of water during the summer and transfers to the tourism and agricultural sector on the coast of the Aude department. However, growing demand, caused by the combined effects of increasing agricultural irrigation, population growth and climate change, could disrupt the current balance. The task in the coming years will be to find the best mix between measures to save water and efforts to mobilise new resources (groundwater, transfers between basins, desalination) in order to satisfy the various needs and to ensure minimum environmental flows in each of the sub-basins.

An HEM was developed as part of a research project to formulate a least-cost programme of measures designed to avoid water shortages in the river basin up to 2030. The theoretically optimal programme of measures in terms of its cost-effectiveness was produced taking into account the interactions between the upstream and downstream sections (which a standard cost-effectiveness analysis cannot do), the interannual variability of the climate and the hydrological system, and the possibility of optimising releases from the dam. The model was then used to **quantify potential trade-offs between different management objectives.** It estimated the different costs of the programme of measures depending on variations in the minimum environmental flows (both higher and lower). It also served to calculate the **cost of measures made necessary by assumptions projecting increases in irrigated land.** All this information is useful for local stakeholders in making the necessary trade-offs between different objectives, namely economic development, the security of water supplies and improvements in the ecological status of environments. For example, the measures entailing the greatest amount of infrastructure and the most costly to implement, e.g. desalination or use of ground-water, would be necessary only if irrigation is significantly developed. If irrigation is not developed to such a high degree, measures to save water, e.g. improvements in the efficiency of water supply networks and of irrigation, would be sufficient.


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Various climate-change scenarios were also built into the HEM. The comparison of the programmes of measures corresponding to the different scenarios revealed a number of **"no-regret" measures such as improvements in the efficiency of drinking-water networks and of irrigation** that would be necessary whatever the climate-change scenario selected.

Figure 4. *Water stored in the Monts d'Orb reservoir during the fall and winter is returned to the river in the spring and summer.*

Box 2

Model for least-cost optimisation of a programme of measures for the management of water quality in the Jucar basin (Spain)

The Jucar basin in Spain (22 400 square kilometres) was selected as one of the pilot basins in Europe for WFD implementation. A number of methods were tested for the economic analyses required in setting up a programme of measures for a river basin. In a partnership between the Jucar river-basin authority (the equivalent of a Water agency in France) and the Valencia technical university, a hydro-economic model was developed to draft a cost-effective programme of measures targeting quality issues, i.e. the good status of the water bodies in the Jucar river and its tributaries. The model served to prioritise measures to reduce point-source pollution throughout the river basin, notably reductions in concentrations of organic matter and phosphorous in the water discharged from wastewater-treatment plants (WWTP).

This type of integrated model produces more useful data than a standard cost-effectiveness analysis that is based simply on ratios of measure effectiveness in reducing pollutant concentrations to cost. The HEM integrates the cumulative effect of several water-quality management measures in WWTPs located on different water bodies throughout the river basin and can thus simulate the upstream-downstream interactions due to the links between water bodies and dilution taking place as the water moves downstream. By taking into account the hydrology of the river basin, this type of HEM can provide basin managers with the data required to optimise the investments made to improve WWTPs.

Sources : López-Nicolás A. (2010), Comparativa de análisis coste-eficacia y optimización para la determinación de un programa de medidas para el cumplimiento de los objetivos ambientales de la Directiva Marco del Agua. Aplicación al sistema de explotación del río Júcar . Proyecto Final de Carrera. ETS de Caminos. Universidad Politécnica de Valencia.
Confederacion Hidrogafica del Jucar (2014), Memoria-Proyecto del Plan hidrológica de cuenca.

Box 3

III- Hydro-economic models and resource allocation

Which water-allocation rules generate the most added-value for the river basin?

In other countries, HEMs are generally used to determine how best to share water resources among consumers, in other words to devise the water-allocation system that maximises the economic benefits for the area as a whole. This problem arises in particular when managers are confronted with demand for water greater than the available resources and are in a position to make changes in the quantities allocated to various water users. They must decide on trade-offs between multiple types of uses (production, consumption, amenities, etc.). HEMs developed for this purpose are based on optimisation criteria targeting the water-allocation scheme that maximises the sum of benefits produced by water usage, while taking into account certain management rules.

An application example in California

■ Context

Water resources in California are characterised by uneven distribution over both space and time. Most of the resources are located in the north, whereas most of the population lives along the coast, particularly to the south, and while the winters are humid, the summers are very dry. Tremendous infrastructure for water storage (dams, artificial recharging of groundwater) and transfer (some 15 systems ranging from 200 to 1 000 kilometres in length) has been built in attempts to meet constantly increasing demand (see Figure 5). In that no free resources still exist, the current policy attempts to optimise water use by encouraging those uses generating the greatest economic value for the area as a whole. The objective is to ensure local economic development using a resource that has become scarce, while enforcing environmental-protection criteria, notably the need to maintain a sufficient discharge in the Sacramento-San Joaquin delta and to stabilise the levels of over-exploited groundwater.

■ The HEM used in California

The CALVIN (CALifornia Value INtegrated Network) model was designed by the University of California in Davis. It describes how the hydro-economic system in California functions, notably the driving hydrological and economic forces and their links with the water resources available in the state. A particular objective of the model is to optimise the operation of hydraulic infrastructure and to improve its overall economic performance. CALVIN was developed to cover the Central valley, San Francisco bay and Southern California. These three parts of the state cover five large river basins representing 92% of the total population (30 million inhabitants) and 88% of the irrigated farmland (2.3 million hectares).

Though the model is used for a number of applications (adaptation to climate change, planning, assessment of water-management instruments, etc.), the primary design goals were to:

- determine the allocation of water between various uses (drinking water, irrigation, hydroelectric generation, etc.) that maximises the benefits derived from water usage for the area as a whole;
- estimate the impacts of other allocation systems, the corresponding benefits and the consequences for water resources.

CALVIN showed that by 2020, the climatic conditions in the state will have reached a point where the system will no longer be capable of meeting the demand of all the household consumers located primarily in the western and southern sections of the state. The losses incurred by the shortage could reach almost 1.2 billion €$_{2004}$ each year[5]. However, a new allocation of the available resources to the uses generating the greatest economic value could reduce the losses to 153 million €$_{2004}$ per year and cut the water deficit in half for the state as a whole (see Table 1, page 12). To achieve that result, the model analysed a number of allocation schemes and determined that transfers from the agricultural sector to the urban sector and transfers between regions were the best solutions.

5. *Monetary values are expressed in €$_{2004}$ because the calculations were carried out using 2004 data. They have not been corrected for inflation occurring since 2004.*

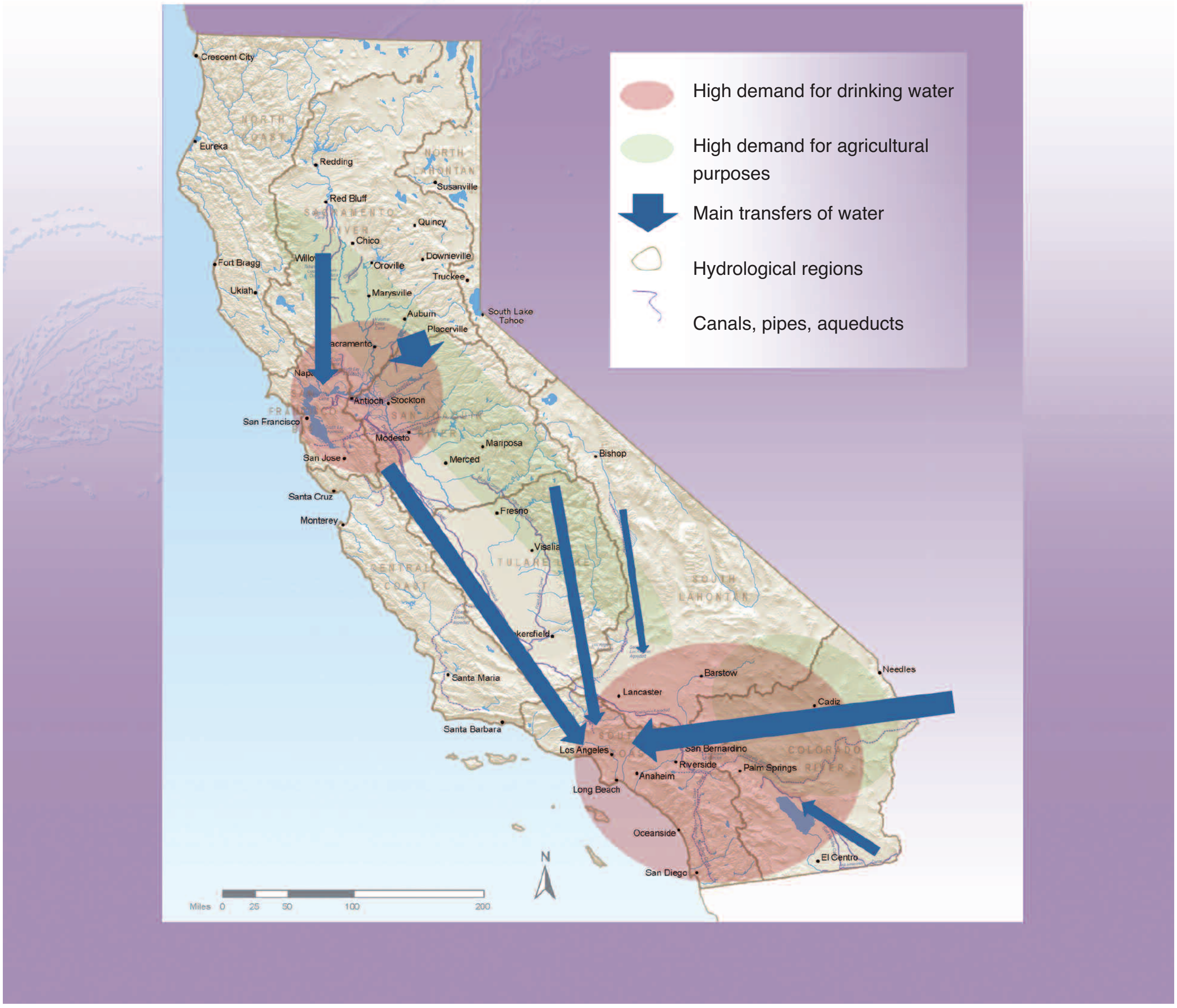

Figure 5. *Map showing the main water transfers in California in 2013. Source: adapted from the California Water Plan, updated in 2013.*

The results showed in particular that a majority of the transfers should take place within Southern California and within the Lake Tulare basin. In Southern California, transfers from the agricultural region in the East, not far from the Colorado River, to the urban areas of Los Angeles and San Diego, on the coast, would alone represent a gain of 700 million €$_{2004}$ compared to the situation without any transfers. The greatest reduction in abstractions would benefit the Colorado river, where abstractions for agricultural needs would be reduced by almost 12%. Enhanced flexibility in the operation of infrastructure and joint management of both surface water and groundwater would also contribute to reducing the economic losses caused by the shortage of water in the region.

More recently, the model was used to assess the impact of various climate-change scenarios on the overall performance of the hydro-economic system in California up to 2050.

Table 1

Economic results of optimised water allocation between consumers in California up to 2020. Source: adapted from Jenkins et al., *2004.*

	Scenario 1 Allocation rules for current resources	Scenario 2 Optimised allocation of resources	Difference between scenario 2 and scenario 1
Water volumes (million cubic metres per year)			
Drinking water	7499	8102	+8%
Agriculture	21952	21919	-0.15%
Total	**29451**	**30021**	**+1.9%**
Economic losses (cost of shortage due to climate change) (million €$_{2004}$ per year)			
Drinking water	1203	131	-89.1%
Agriculture	25	22	-12%
Total	**1228**	**153**	**-87.5%**

Outlook for France

In France, this type of model would be useful for studies on resource allocation in large river basins such as the Rhône (comparison of different projects to transfer water to other basins from the Rhône) and for efforts to allocate abstractable volumes on a smaller scale, e.g. for an SBMP (sub-basin management plan). An example in France is an HEM currently being used to study the consequences for the agricultural economy and groundwater in the Beauce[6] region of new allocation rules and possible water transfers. This type of HEM could provide decision-makers with information on environmental and socio-economic impacts arising from new allocation rules and thus assist them in determining whether to modify the current rules.

IV- Hydro-economic models and assessment of economic water-management instruments

What water-pricing policies generate the most added-value for the river basin?

Due to their capacity to integrate economic and hydrological aspects of water management in a single framework, HEMs are particularly well suited to assessing the effectiveness of economic instruments. These instruments attempt to modify the behaviour of consumers by changing the price signals. A distinction is made between economic instruments that directly impact the price of the resource (tariffs, taxes and fees, subsidies, etc.) and those that create new markets (tradable water rights, etc.). In both cases, the objective is to financially encourage desirable behaviour and/or to discourage undesirable behaviour. Economic instruments may pursue an array of objectives, including limiting demand for water, guaranteeing equitable access, incentives to encourage those uses that generate the greatest added value for the region, incentives to pollute less, etc.

6. Graveline (2013). Contribution of mathematical programming models to adaptation by farmers to water-management policies and global change. Doctoral thesis. Chapter 7. Trade-offs between irrigated agriculture and groundwater level for alternative water policies.

In France, pricing is the economic instrument most commonly used by the managers of drinking-water and irrigation utilities. A change in tariffs results in consumers modifying the quantities of water drawn. On the scale of a river basin, a change in the price of water by one or more suppliers can impact the quantities consumed by the customers of those suppliers and in turn the quantities made available for other uses in the basin.

Given that the economic value of water varies depending on the use, the new allocation system can modify the economic value drawn from water usage for the river basin as a whole. HEMs can be used to assess the economic impact of different pricing policies and determine the system of tariffs that generates the most economic value from the water used in the basin.

Example of an HEM used for household water prices in the upper Rio Grande valley

■ Context

The Rio Grande is a river whose lower section marks the border between the United States and Mexico. It originates in Colorado, crosses New Mexico and serves as the southern border of Texas before flowing into the Gulf of Mexico. Its river basin is currently considered in deficit. The situation will probably worsen in the future due notably to stricter environmental-protection criteria, the current trend toward falling water quality, climate change and population growth in the region. The upper Rio Grande valley supplies three major cities with water, namely Albuquerque (New Mexico), El Paso (Texas) and Ciudad Juarez (Mexico), as well as 400 000 hectares of irrigated land in the two countries. North of the international border, high levels of arsenic in the river waters mean that towns must invest in increasingly costly treatments that could have a significant impact on water bills of households in the future. A number of different pricing schemes could be selected to ensure effective management of the water resources in the river basin.

■ The hydro-economic model used

A model was developed by U.S. and Spanish academics to determine the pricing scheme generating the most economic value from the water resources in the upper Rio Grande valley, while meeting certain conditions dealing with maintaining equity among consumers and the sustainability of water provision. The model covers the upper Rio Grande valley.

Eight consumption sectors were analysed, located in the states of Colorado, New Mexico and Texas (see Figure 6, page 15). Agricultural demand functions were calculated using an economic model developed for the San Luis valley (Colorado) and adapted to the specific conditions of the upper Rio Grande valley. Demand functions for household water were calculated on the basis of various econometric studies. It was set for two categories of households, having annual revenues either above or below the poverty line as defined by the U.S. Census Bureau. Two types of constraints[7] were taken into account:

- environmental regulations concerning water quality;
- four hydrological constraints pertaining to the international treaties between the U.S. and Mexico, the U.S. Endangered Species Act and agreements between and within regions governing the sharing of water between the neighbouring states.

The model was developed in 2008 to assess the economic impact of different pricing schemes for household water in the cities of Albuquerque (New Mexico) and El Paso (Texas). It determines the greatest economic value from household, agricultural and environmental uses in the upper Rio Grande valley based on three pricing schemes for household water:

- the current pricing policy where resource allocation is based exclusively on meeting the hydrological, environmental and legal constraints specific to the river basin. No transfers from agricultural to urban uses are allowed under this scheme;
- a marginal cost[8] pricing policy in which the environmental and legal constraints are met, and resource allocation among uses is the result of efforts to maximise benefits, where transfers are authorised;
- a progressive, social pricing policy where prices increase with the quantities consumed and with the revenues of households. This type of pricing policy attempts to limit water bills for the poorest households while encouraging all households to limit their consumption.

7. The term "constraint" is understood here to mean a rule for an optimisation model.
8. For the marginal-cost pricing policy, the price of water is equal to the total cost for the production, transport and distribution of the last cubic metre supplied. According to standard economic theory, marginal-cost pricing produces the maximum benefit while achieving the best economic balance by setting a minimum price that covers the costs of the water company and the necessary investments.

Table 2

Economic results of three pricing policies for the upper Rio Grande valley. Source: adapted from Ward et al.*, 2009.*

	Current pricing policy (1)	Marginal-cost pricing (2)	Difference between 2 and 1	Progressive, social pricing (3)	Difference between 3 and 1
Water volumes (million cubic metres per year)					
Drinking water	131242	178238	+35.8%	170 097	+29.6%
Agriculture	1594399	1593535	-0.05%	1 593 782	-0.04%
Total	**1725641**	**1771773**	**+2.7%**	**1 763 879**	**+2.2%**
Economic benefits (million €$_{2006}$ per year)					
Drinking water	406	444	+9.4%	443	+9.1%
Agriculture	157	157	0%	157	0%
Total	**563**	**601**	**+6.8%**	**600**	**+6.6**

The greatest net economic benefits are produced by the marginal-cost scheme and the lowest by the current scheme. A consequence of the marginal-cost scheme would be an increase in the drinking-water volumes (Albuquerque and El Paso) and a drop in water for the agricultural sector (New Mexico), the sector for which the economic benefits drawn from water use are the lowest. This pricing scheme consequently produces the greatest economic value, but also results in the largest quantity of water consumed (+2.7% compared to the current situation). It should be noted that the benefits generated by the progressive, social pricing scheme are almost as high as those for the marginal-cost scheme (a difference of only 1 million €$_{2006}$, i.e. 0.16%), whereas the increase in water consumption is lower, just 2.2% more than the current situation. In terms of preserving water resources and social equity, the progressive, social pricing scheme would appear to be the most suitable in that the price paid by the lowest-income households corresponds better to their capacity to pay.

In this example, the HEM made clear the economic impact on the river basin as a whole of a progressive, social pricing scheme applied to two cities in the basin.

Public decision-makers must take numerous criteria into account when formulating pricing policies, e.g. equity between water consumers. That being said, the model developed for the South-West of the U.S. highlights the value of assessing, among other criteria, the cost-benefit ratio in determining the respective merits of one pricing scheme compared to another.

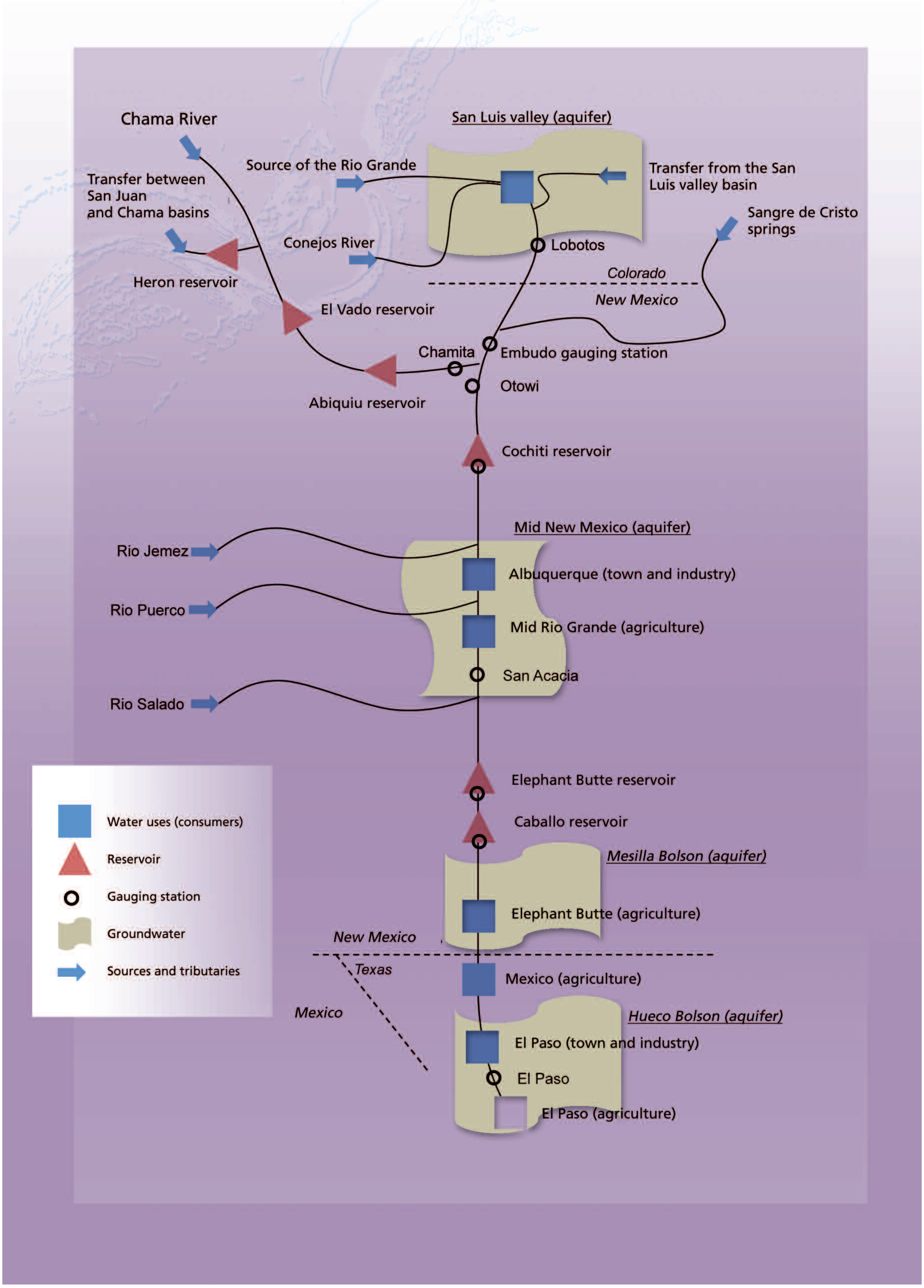

Figure 6. *Diagram showing the upper Rio Grande valley. Source: adapted from Ward F. A., Pulido-Velazquez M. (2008).*

Outlook for France

In France, the law on water and aquatic environments (LEMA law) encourages water companies to set up incentive pricing schemes to reduce consumption. A number of possible pricing systems exist, both for the agricultural sector and for domestic uses, e.g. elimination of the fixed price in a combined fixed/variable price structure, seasonal prices, progressive prices, etc.). HEMs can provide decision-makers with information on the economic value to be gained from changing the pricing policy for the various economic sectors using water, taking into account the interactions that exist within river basins. They can also contribute to assessments of fees applied to abstractions, structured to take into account the qualitative and quantitative status of the water body.

More generally, this type of HEM could be used for relatively large areas to calibrate different economic instruments to ensure that they correctly reflect the qualitative and quantitative pressures weighing on the available resources.

V- Conclusion

Hydro-economic models are a further step in the development of economic-assessment methods and they complement the standard techniques (cost-benefit analysis, cost-effectiveness analysis). They provide a comprehensive cost-benefit analysis of the water management for entire river basins or even wider territories by taking into account an array of complex processes and interactions (upstream-downstream links between infrastructure facilities, between groundwater and surface water, between productive and recreational uses). They contribute to producing a new perspective on environmental issues and are particularly useful in areas where significant tensions concerning water resources have arisen.

That being said, these models are still not widely used in France to assist decision-making on management policies for water and aquatic environments. Among other reasons, this may be because economic analysis is not often used as a decision aid and also because water managers are not always familiar with the models and data collection and processing are long and costly.

Using the specific examples from the U.S., the U.K., Spain and France, this document illustrates the potential value of HEMs in answering the questions confronting water stakeholders (see Table 3).

It shows that the investment in a hydro-economic model is worthwhile because:

- it is an integrative tool that can be used to explore and compare an array of scenarios;
- compared to standard economic analyses, it has a decided advantage in that it can be updated, expanded and improved in step with gains in scientific knowledge. In this sense, it is a dynamic and durable tool that can be reused during the different planning cycles of water management.

Hydro-economic models aim at enhancing the debate preceding decisions on water-allocation schemes. However, they do not pretend to take into account all aspects of the issues and concerns weighing on water management (environmental, political, ethical, social, technical, economic aspects, etc.). In a budgetary context where managers must rationally decide on investments and are confronted with a general public that has difficulty in seeing environmental policies as opportunities for economic development, hydro-economic models can assist water stakeholders in establishing dialogue among users and in better understanding the complex interactions that exist between hydrological systems and the uses of water that depend on those systems.

Table 3

Partial list of hydro-economic models.

Reference	Country	Purpose for which the HEM is used
Hydro-economic models and selection of a programme of measures		
Padula *et al.*, (2013)	United Kingdom	The model was developed by six private water companies and attempts to determine 1) **the most cost-effective programme of measures capable of satisfying each year urban and agricultural demand in SE England over the period 2015 to 2039**, while complying with all environmental-management rules, and 2) the **optimum schedule** for the launch and execution of the various management measures planned over the period.
Girard *et al.*, (2015)	France	The model, designed to cover the Orb River basin, is used to devise the least-cost programme of measures best suited to **the reduction of deficits up to 2030**. It can also be used to assess the cost trends of the programme of measures as a function of various environmental objectives. Finally, the HEM is capable of devising programmes of measures suited to **different climate-change scenarios.**
López-Nicolás A. (2010)	Spain	A hydro-economic model was developed to draft a cost-effective programme of measures targeting the **good status of the water bodies** in the Jucar river and its tributaries. The model can prioritise **measures for point-source pollution reduction** throughout the river basin (concentrations of organic matter and phosphorous in the water discharged from WWTPs).
Hydro-economic models and resource allocation		
Jenkins *et al.*, (2014)	United States	The CALVIN (CALifornia Value Integrated Network) HEM was developed to 1) devise the **system to allocate water among different uses** (drinking water, irrigation, hydroelectric generation, etc.) that produces the greatest benefits for the area as a whole and 2) assess the impact that **other allocation rules** would have on water usage, the corresponding benefits and on resources.
Reynaud *et al.*, (2008)	France	The purpose of the MOGIRE HEM (model for integrated management of water resources) is to optimise water allocation between household and agricultural consumers, taking into account a number of **scenarios for the future** (agriculture, climate, economy). It has been used for the Neste River basin (Midi-Pyrénées region).
Fisher *et al.* (2002)	Israel, Jordan, Palestine	The WAS (Water Allocation System) model is used in the Middle East to determine water-allocation rules and infrastructure needs for water production (desalination) and distribution, in view of generating the maximum economic benefits and thus highlighting the value of regional cooperation in water management.
Houk *et al.*, (2007)	United States	This model identifies the **agricultural regions producing the least added value** per cubic metre of water consumed by agriculture in order to provide local decision-makers with information on **cost-effective water transfers** ensuring sufficient minimum environmental flows for the endangered species and habitats in the Platte River (a tributary of the Missouri River).
Bielsa *et al.*, (2001)	Spain	This HEM is used in the NE section of Spain to devise the water-allocation system for two competing uses (agriculture and hydroelectric generation) that maximises at all times the economic benefits provided by the water in the Vadiello reservoir. The results show that for all the scenarios tested (dry periods, increases in irrigated land), the most cost-effective solutions involve water transfers between consumers.

Hydro-economic models and assessment of economic water-management tools		
Ward *et al.* (2009	United States	A model was developed by U.S. and Spanish academics to determine the **pricing policy** generating the greatest economic value from the water resources in the upper Rio Grande valley, while meeting certain conditions dealing with maintaining **equity among consumers** and the sustainability of water provision.
Pulido-Velazquez *et al.* (2013)	-	The HEM can be used to develop a simulation method for different water-pricing policies as a function of the **marginal opportunity cost** of water resources. The method was developed with a theoretical application to explain how a simulation model and an optimisation model can produce a **step pricing policy as a function of the water volume stored in a reservoir.**
Srinivasam *et al.* (2010)	India	An HEM was developed to model the drinking-water distribution system of the city of Chennai (population four million). The policy had a double goal, namely 1) better understand the causes of numerous disruptions in the supply of drinking water in the city during the dry periods in 2003 and 2004, and 2) assess the impact of various water-management tools designed to address the causes of the malfunctions.
Brown *et al.* (2006)	India	On the basis of a **price for groundwater that varies as a function of the available quantities and rain forecasts** for the following monsoon in the province of Tamil Nadu, the model assesses the impact on the benefits drawn from water in the region, on the income of farmers and on groundwater levels.


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A hydro-economic model takes into account all uses of water in a region.

For more information

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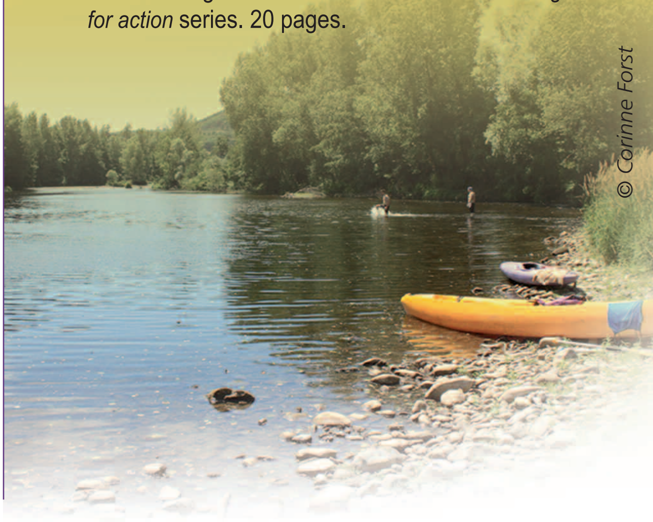
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