STRICT AQUIFER CONTROL RULES VERSUS UNRESTRICTED GROUNDWATER EXPLOITATION: COMMENTS ON ECONOMIC CONSEQUENCES

E. CUSTODIO,
Prof. Polytechnic University of Catalonia. Int. Course on Groundwater Hydrology and ETSICCP/Dept. Ground Eng., Jordi Girona Salgado, 31, 08034 Barcelona, Spain

ABSTRACT

Groundwater exploitation produces economic benefits through water application in agriculture (mainly irrigation) and industrial activities, and accomplishes a socio-economic role in supplying water for urban and rural areas. Exploitation-related problems may have a direct or indirect influence upon economic costs as well as being the cause of social protest and environmental changes. They represent a real cost, although its evaluation is a difficult and controversial task. Generalized groundwater level drawdown; increased cost of pumping; more expensive wells; in some cases, impairment of water quality; reduction of flow and even dry-off of water courses, springs and wetlands, are some of the problems involved. Unrestricted development of an aquifer may lead to excessive withdrawal, thereby magnifying the above - mentioned problems; but at the same time it may create conditions for the efficient use of water, and even if the cost of water is high, the weight of water cost on the local economy is reduced. In some extreme situations there is the danger of highly undesirable social problems or the practical loss of the aquifer, but existing experience show that some corrective actions intervene to avoid catastrophic situations. With fully-regulated development many of the exploitation-related problems are minimised and water production costs are kept to a reasonable level, thereby avoiding undesirable social stress and the risk of dangerous breakdowns in the socio-economic structure. But, generally, there is little intrinsic incentive for efficient use of water. The incidence of the cost of water in the local economy is therefore high. Water-related economic development is generally small when water resources are scarce. A middle-of-the-road solution, somewhere between unrestricted and fully-regulated development, would seem to be the answer, but controls are needed to avoid intrinsic unstabilities. Groundwater user's associations, a coordinating higher Water Administration and a well-conceived flexible Water Plan including measures to foster efficient use of water seem to be necessary elements for some degree of stability.

1 INTRODUCTION

Groundwater exploitation is a common source of fresh water. Under arid and semi-arid conditions this may constitute the major source of water in continental, coastal and island areas. Relatively recent developments in well construction and pumping machinery have contributed dramatically to the fast development of local groundwater resources, especially for rural uses (dispersed population, small towns, irrigated agriculture, cattle rising), small industrial settlements and large, low-density residential areas.

Groundwater development, when compared with surface water undertakings, does not generally need long contruction periods and production may closely follow on demand expansion and fluctuations. This explains the preferential development of aquifers by private owners (if they exist), small enterprises and local public organizations. In many instances the development of large surface water developments is undertaken by economically powerful entities, able to obtain low-interest public funds or subsidies. This introduces a factor of economic distortion.

Short contruction times and adaptability to demand are desirable characteristics when financial resources are scarce and capital interest rates are high, as frequently has been the case over the last decades. As a result, groundwater, when available and of sufficent good quality, has been preferred.

In many situations only poor countries have continued undertaking large waterworks -- mostly large surface water developments -- paying off heavy loans for capital resources coming from abroad. This has meant increasing international debt and difficulties in the repayment of loans. Experience shows that these huge, long-term projects frequently present internal flaws and contain errors in forecasting of production, management, feasible markets for products and even technical performance. A common situation is the need for additional loans to be able to commission works once constructed, thus adding to existing financial difficulties. In some cases this type of development has been imposed or "highly" recommended by international public or private organizations, since they see these huge projects as a ready market for their own products, technologies and services, regardless of the type of water development the region really needs and is able to manage to improve its own economy and living standards.

Often, groundwater development, progressing at the same rate as actual economic growth, would be a more effective, cheaper and less risky solution. This is true even when the long-term final solution is the larger undertaking - built, of course, at the right moment, when there is a well-established local economy, with sufficient managerial capacity and using all possible water resources, integrated in a regional water system. Conjuntive use of existing surface and ground water is a final goal for efficient use of water resources (Sahuquillo, 1985).

2 GROUNDWATER OVEREXPLOITATION

Groundwater exploitation is not without problems. A series of adverse side-effects can easily be identified, many of them generally related to "overexploitation", in the broad sense of the word, although true overexploitation - abstraction greater than aquifer recharge - does not necessarily occur. Overexploitation is at present a key issue in water laws, but unfortunately it is a poorly-defined term, used by people with insufficient knowledge of geohydrology. Thus conceptual, assessment and argumental errors are easily introduced, and sometimes translated into inadequate laws and regulations.

Some common problems related with intensive groundwater exploitation are:

- Decrease in river and spring flow, sometimes accompanied by the reduction and even disappearance of wetlands and riparian vegetation belts. This is an unavoidable consequence of water winning. Adverse consequences may be minimised in some instances when aquifer properties allow the effects of incidental peak demands to be delayed until next recharge season. This means taking advantage of the aquifer hydraulic diffusivity by siting wells correctly. Careful management is needed to avoid the most acute consequences.
- Regional groundwater level drawdown. This is also an unavoidable consequence of groundwater exploitation. This is needed to transform natural outlets of the system into water resources available at the pumping wells. It means deeper and, therefore, more costly wells and high exploitation costs due to increased energy consumption. During the transient period, water levels go down continuously, thus progressively increasing the cost of water. This is due to increased greater elevation, the substitution or deepening of wells. Consequently pumping machinery has to be replaced progressively, or it results in the use of low performance pumps and installations well off their working point.
- Possible, and sometimes serious, impairment of water quality. This may be due to the mobilization of old, poor quality water stored in slow-flow parts of the aquifers and/or aquitards of the groundwater system as a consequence of deep wells or water galleries and enhanced water gradients. In coastal areas, sea-water and/or old saline waters can easily be mobilized to encroach fresh water sections of the aquifer or to produce saline upconings below wells. There is a loss of usable aquifer volume, some wells have to be abandoned and water may become unfit for its intended uses if costly mixing schemes with imported new water or using desalting plants are not available.
- In some cases, land subsidence. Though this is not a common consequence, when it occurs, serious economic problems may arise. The area is more prone

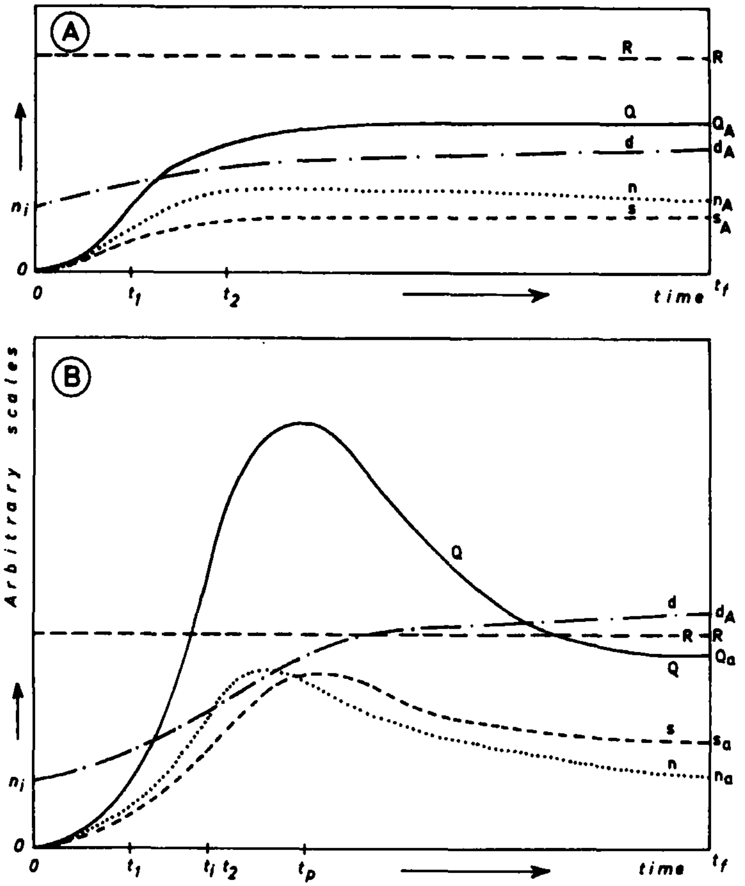

Fig. 1 - Evolution of abstraction, regional groundwater level drawdown, number of wells and depth of wells in an aquifers. The exploitation starts at time 0. A; under strict water planning to avoid exploitation conflicts. - - B; without exploitation rules.
R = total aquifer recharge. Q = mean regional groundwater level drawdown. n = number of wells. d = mean depth of wells.

to water flooding, and water canals and surface channels - even civil constructions and buildings - can be badly affected as well. In shallow karstic areas (including areas with gypsum), the water level draw-down may increase the rate of dangerous land collapses and sink-hole formation.

The closing of wells tend to restore previous hydraulic situations, except for subsidence, but this change-over to less groundwater-stressed circumstances may also be a problem. During high exploitation periods, drained-out marshy, swampy and shallow water-table lands are frequently occupied by human settlements, even extensions of urban areas. The recovering water-table after cessation or reduction in groundwater abstraction may create well-known economic problems and losses through water-logging of underground constructions such as parking-lots, subway tunnels, low-level road crossings and cellars (Custodio and Bayó, 1986).

3 FULLY-CONTROLLED EXPLOITATION VERSUS UNCONTROLLED EXPLOITATION. ECONOMIC ASPECTS

The fear of above problems frequently leads to the establishment of aquifer exploitation rules, included in water laws, regulations, exploitation permits, and water plans. They intend to avoid the negative side effects of exploitation - overexploitation - but they may also counteract some of the advantages inherent to groundwater, due to inherent aquifer characteristics.

The consideration of two extreme situations may help in the understanding of the differences between unrestricted and controlled groundwater exploitation and their economic consequences. Figure 1 is inspired on some old reports published in arid SW United States, and helps to clarify the following explanations.

Let us assume the following scenario in an aquifer under natural conditions before time zero. At time zero the area begins to develop economically. Dry farming is progressively being converted to irrigated land, towns grow and some industrial settlements are planned. Increasing water needs are supplied by wells drilled in a thick aquifer underlying the area. The area is a continental one, semi-arid, without serious water quality problems in existing groundwater reserves. Aquifer recharge (R in figure 1) is by rainfall infiltration over the area and by percolation of flood water from local creeks. Its mean value is equal to aquifer discharge, which concentrates along a stream originating in the area, in the form of diffuse outflow, some localized springs and some small wetlands and phreatophytic plant belts along the river.

The area under consideration is part of a much larger economic unit (region or country) able to supply financial resources in the form of loans and to absorb the production, but that cannot supply additional water resources at low cost.

The first irrigation wells start at time zero, and due to the economic success of the investment, other farmers and local organizations begin to imitate them. As a consequence there is a close-to-exponential growth in groundwater demand and number of wells. Regional water levels decline, reducing the outflow to the river and springs and the wetland extension. The newest wells are deeper than the older ones. Existing wells must frequently be extended and machinery replaced.

At time t_1, a worried administration, on its own initiative or as a result of public pressure, decides that it is time to introduce regulations to avoid further damage and to protect already existing economic development. Total recharge R is estimated, and after a thorough geohydrologic study it is decided that the acceptable maximum drawdown is s_A (fig.1A), This allows to withdraw groundwater from existing wells at a price acceptable to established economic activities and conserve some environmental values.

The implementation of rules takes some time and these do not become effective until time t_2, but demand increase ceases to be exponential and tends to level off. Finally a steady total abstraction Q is attained, compatible with maximum allowable drawdown s_A. After time t_2 only a few new exploitation permissions are granted, and those existing previously, duly "legalized", are guaranteed. The number of wells peaks shortly after time t_2 and then slowly decreases as old wells are replaced by more efficient new wells, these being slightly deeper to adapt to new aquifer conditions.

At time t_f an almost stationary situation is attained in which the difference $R-Q_A$ is the part of the recharge still outflowing to the river, springs and wetlands. They are not fully destroyed.

New water-related economic developments under similar conditions are not possible since there is no more water available, unless water users decide to convert to activities yieding more economic output per unit of applied water. There is little incentive to do this since there is at present a kind of guarantee of the water price that does not favor investments aimed at "saving" water. The relatively low price of water is commonly accompanied by low efficiency uses and relatively high water losses. A part of the losses may find its way to the aquifer through infiltration and can be recovered later with some impairment of quality, meaning an energy and economic loss without profit. To improve the situation, rules to stimulate better water use have to be introduced, generally through taxes, subsidies for saving investments or fines. This may result in a heavy increase in bureaucracy.

Let us now assume that at time t_1 no control at all is established in groundwater abstraction. Unrestricted development continues, and as a consequence the continuous growth of total abstraction, drawdown and number of wells. Consequently the mean depth of wells also increases conspicuously.

Assuming that there are still agricultural land and industrial sites to be developed - even if they are of marginal interest - at about time t_i water begins to be expensive (increased elevation, deeper wells, more sophisticated pumps) and conflicts among water users become frequent. Most natural outlets of the aquifer have dried off, possibly exarcerbating protests from local nature conservationists and concerned inhabitants.

This leads to a decline in the growth rate, and a tendency to level-off, but this is not possible due the existing degree of overexploitation. At time t_p a total abstraction maximum (peak) is attained and a relatively fast decrease may follow. Water costs are now so high that uneconomical industries and farms cannot continue their activities and are thrown out of the market. Many others are obliged to make more efficient uses of water. This means investing in water-saving technology, improved irrigation methods, new industrial processes, new crops demanding less water and more intensive in man-work, and sharp reductions of water losses in water networks. As a consequence with a smaller amount of water, economic output is maintained or even increased - usually as a result of using more advanced, sophisticated technology.

The period of recession finishes with a total abstraction Q_a, generally closer to R, the total recharge. Environmental changes are much greater and final regional draw-down, s_a, is higher, with a total number of operating wells not very different from the regulated case, although they are much deeper. Water abstracted is still more costly than in the regulated case, but the incidence of water on economic output is not as great since it is much more efficiently used. The cost of goods produced is much less water-related and depends much more on labor cost, technology and capital interests than in the first case (strict regulation). Even the improved economic situation may allow to rise economic resources for environment regeneration and conservation.

In the absence of strict exploitation rules at that time, the value Q_a is by no means a stable final value, since the dynamics of the economy may produce fluctuations that follow the development, the concurrence and the introduction of new products and technologies and even the need for nature conservation. Water problems related to the environment tend to be solved by technological means. Artificial recharge and substitution of some agricultural water for reclaimed sewage water are some of them (Custodio, 1985).

Previous comments may point to the unrestricted development scheme as the most desirable, but it may be not always true. Aside from important possible negative effects on the environment, the cost of which is not easy to calculate, the situation after time t_p must be considered in more detail.

A relatively broad peak followed by a slow recession limb indicates a progressive adaptation to changing circumstances. This means that social stress is contained within tolerable limits, no serious economic losses have been incurred by abandoning investments that have not been fully realised and the fraction of the jobless population attributable to this cause is acceptable. Existing experience shows that this is the most frequent situation in areas integrated in a larger economic unit.

But an abrupt cessation of growth and a rapid recession is generally accompanied by an undesirable rate of job loss, early abandonment of investments, great social stress and unrest, and possibly flagrant injustices. This is the ugly side of a process that cannot usually be solved on the spot by administrative and legal means. When enforced, the measures taken come late, and in most cases are ineffective when they do not in fact contribute aggravating the situation due to bad timing or inability to adapt to rapidly changing circumstances. Situations like this may occur most frequently in coastal aquifers and in areas where serious impairment of groundwater quality is possible.

In some circumstances, water treatment and desalting may help to avoid a sharp decline in water availability if the great cost involved is acceptable and the facilities are provided in due time. In other circumstances, part or the whole of the aquifer has to be given up for water supply, except for some cooling uses. Then, final abstraction can be even less than in the regulated case, at a much higher cost.

In the case of an aquifer with a small recharge rate compared with water needs, true overexploitation may appear. In some circumstances there is the danger of the aquifer being emptied before serious economic stress appears. A sharp reduction of water production is inevitable, with all the undesirable consequences mentioned above. Much more efficient use of water will not solve the labor and social problems that will appear, and the development of new water resources, generally by importation - or by sea water desalination - is the only alterative to solve the problem. But this solution is only effective if necessary steps are taken well in advance - in many cases long before the onset of the period when charges occur most rapidly. On-the-spot solutions by public organizations are generally too expensive, short-lived and drain economic resources from potential long-term solutions. This, in turn, creates more problems which affect neighbouring areas. More often than not, they are no more than short-lived political solutions to defuse an explosive situation rather than real solutions to the problem. Under these circumstances, economic aspects are disregarded, but the loss of economic resources is felt later.

All the comments made above, even though they refer to a very simplified hypothetical situation and in a purely descriptive manner, point to the fact that aquifer development is closely linked to economic and social issues and that the cost of water has, in many instances, a decisive influence on the evolution of water demand.

4 CORRECTION OF ECONOMIC AND SOCIAL PROBLEMS

The economic and social consequences of strict aquifer control rules versus unrestricted groundwater exploitation only represent an oversimplified comparison between two extreme situations that are rarely found in reality. Both strict control and truly unrestricted development present a big number of intrinsic and aquifer-dependent circumstances that greatly affect their economic and social efficiency.

Unrestricted groundwater development looks like yielding long-term efficient results if a breakdown at the stage of maximum withdrawal can be avoided or does not occur. But in the event of a breakdown, serious economic and social damages may occur that a responsible human conscience cannot admit. The situation may adversely affect local and even national politics and give rise to unpalatable social unrest.

A wise combination of both systems should, theoretically, give the best results, but such a combination may become easily unstable from the legal and administrative point of view. Without effective measures, the evolution is towards one system or the other, with all the shortcomings that each system implies. The balance is also very sensitive to changes in government and pressure-group policy orientations - perhaps even magnifying them. Forecasting the results is difficult, and undesirable and harmful wide fluctuations may occur.

A water development plan containing some restrictions to preserve and protect some water quality and environmental values, but largely open to free development, would probably produce good results. This implies that the evolution of water demand and economic values can be reasonably well modelled to enable fairly accurate forecastings. They are needed to introduce or stimulate corrective hydrological and economical measures at the right time. This means that the necessary actions, including the early committment of economic resources and the preparation and implementation of rules for water use and management, must be taken well in advance, before problems appear. This is particularly difficult when economic resources are scarce and short-term political values tend to dominate the region or country affairs.

A Water Plan may appear as to be a reasonable solution as long as the following considerations are borne in mind:

- full water regulation is not in itself an objective. A limited number of generic restrictions may be enough to avoid undesirable side-effects and an eventual breakdown.
- rigid schemes and lists of legally-bounded large-scale works are to be avoided. Otherwise management efficiency and adaptability to changes may be seriouly impaired. Experience shows that rigid schemes have produced costly "hydraulic monuments", at a great economic and social cost and without an adequate benefit.
- forecasts, whenever possible, have to be based in a well-conceived simulation model. Such a model has to be fed with accurate, continuously updated and reliable data. A framework, of medium and long term goals is needed, upon which short term interests, such as short-lived policies and politics, have little influence. Otherwise Water Plans become soon obsolete, useless, and even an obstacle to development and efficient use of water.
- there are means to create or to obtain, in time, the financial resources neccessary to put managerial measures into effect. These would come, either wholly or partially, from the benefits of the groundwater use itself, and would be relatively free from the vicisitudes of short-term policies and politics of opportunity.
- the Water Plan should be revised periodically and should have the legal means for doing so, effectively and automatically.
- the Water Plan has to be co-ordinated with other Plans such as those relative to land use, environmental protection, agricultural and industrial development and economy (taxes, subsidies, richess redistribution,...).
- ill-conceived Water Plans may be worse than no Plan at all, as is the case when behaviour in water resources management is biased (Llamas et al., 1979; Llamas, 1984).

It seems that Water User's Associations have an important role to play in economic management of water resources, and help in controlling the excesses of unrestrictred groundwater development. But once set up, they tend to be conservative so as to protect and perpetuate, in their own interest, already existing situations. As a rule, they try to avoid new developments, thus reducing the opportunities for more efficient and economically desirable uses of water. So, paradoxically, they need the guidelines and norms of a higher level Administration to counterbalance the excesses of a self-overregulation, by introducing more freedom into water management, especially for new developments and in the relationships between different Water User's Associations. This Administration should coordinate, guarantee the possibility of new desirable or neccessary developments, safeguard social and personal rights and supply legal, technical and scientific assistance - all of this with due respect to the freedom of action of Water User's Associations. Here, the paradox of the need for an Administration to liberalize, instead of introducing restrictions, becomes apparent. In reality the task of avoiding excess of conservatism and introducing restrictions come at the same time. Good managerial ability within the framework of a Water Law and a Water Plan is again needed.

5 EXISTING EXPERIENCE

No pure extreme situations can be mentioned as examples. Existing examples are imperfect ones, and are the result of complex situations that have to be treated individually. Careless attempts to generalize are dangerous and may lead to errors. So, only short comments are given on a few well-known situations, mostly taken from experience existing in Spain. Situations in which some kind of unrestricted groundwater exploitation has occurred are clearly more numerous than situations where serious restrictions occur, probably due to the fact that, up to now, groundwater has ussually been linked in some way to land ownership (Llamas et al., 1979). There has also been great difficulty in effectively enforcing groundwater laws and regulations.

In the Lower Llobregat river area (near Barcelona, Catalonia, in NE Spain) intense exploitation has produced an enormous decline in piezometric levels and two conspicuous sea water encoachment wedges (MOP, 1966; Custodio, 1981; Custodio et al., 1986). As a result, serious groundwater problems have been posed due to the increased cost of water, need to abandon salted-up wells and even perennial or temporary dry-off of part of the aquifer. The subsequent recovery of the water table in areas affected by high salinity has created drainage problems in underground structures (Custodio and Bayó, 1986). Artificial recharge with excess river water (Custodio, et al., 1982; Custodio 1985; Miralles and Cantó, 1984) and the creation of a Groundwater User's Association (Ferret, 1983) is helping in controlling the situation, which is being studied by means of models (PHPO, 1985). The weight of water cost on local economy is rather small and decreasing, the strategic value of the aquifer being the main issue. Industries have achieved large reductions in unit water consumptions to decrease pumping costs and reduce the danger of further saline contamination, which implies more costly water treatments and increased corrosion rates.

In the Canary Islands (Spain), specially in Gran Canaria and Tenerife, local conditions of intense groundwater exploitation (SPA-15, 1975, López-García et al., 1981) produce an intense continuous drawdown of ground water levels in the low permeability volcanics, mainly reflected in very high water prices (up to US $ 1 m^3 in summer in water stock exchange centers in Gran Canaria), which reflect the increased cost of groundwater abstraction. The weight of groundwater prices is important in the economy of the islands (MAC-21, 1980). Economic activities change from semi-intensive traditionally-irrigated agriculture (bananas) to intensive irrigated agriculture (tomatos, vegetables and flowers under green-houses, tropical fruits), using highly improved irrigation methods, and to services (tourism mainly), where, with less water consumption more jobs and benefits are produced. Water-reuse is being introduced and desalination is now a "conventional" source of water in Gran Canaria for urban supply and in some instances for irrigation.

On Eivissa (Ibiza) island (Balearic Archipelago, Spain) groundwater development has resulted in progressive salinization, posing serious supply problems. Agriculture has been badly damaged and economic activities have moved towards tourism. An important touristic industry has flourished which is able to pay much higher water prices, and water desalination is now becoming a feasible immediate solution. A similar situation can be found on the Island of Malta - a case complicated by sectorial politic involvements.

In Mallorca island (also in the Balearic Archipelago), due to its larger surface area, different problems arise. Intense groundwater exploitation exists in the vicinity of the capital, Ciutat de Palma, for urban and touristic center supply. Sometimes intense concurrence with irrigation exists. Conspicuous drawdown and salinization is a well-known problem in many areas. But economic benefits from groundwater use allows for water reuse for irrigation. This was established years ago and new projects are under study to try to solve water problems that were considered as conducting to catastrophic breakdowns years ago.

Other examples from continental Spain show similar patterns. In the Tarragona Plain (Southern Catalonia) groundwater overexploitation for recent industrial settlements and agricultural transformations have resulted in very acute water problems (drawdown and salinization), and as a consequence producing a very conflictive social environment. The foresought breakdown has not been produced, in spite of the establishment of a sometimes obscure system of getting and distributing water and even the need for temporary importation of water by tanker. Present local economy allows to pay for a 80 km canal importing water from the Ebro River, now under construction, after solving complicate socio-administrative obstacles, that at the begining seemed unsurmontable.

In the La Mancha Plain, in Central Spain, South of Madrid, the fast transformation of extense areas of dry farming into irrigated cultivation by local inhabitants has been the origin of drawdowns and the almost dry-off of the Daimiel wetland, a park of international interest (López-Camacho and Gurguí, 1983). Otherwise unthinkable water transportation schemes from other basins are now under advanced consideration. Present highly improved economic situation allows for this.

As a last example, true overexploitation of aquifers, up to the practical emptying of some of them (Albacete et al., 1987) is frequent in semi-arid SE Spain (Alicante, Murcia and Almería). Groundwater exploitation has allowed an impressive development of irrigated agriculture. A catastrophic failure seemed unavoidable, but in reality the system is approaching some levelling off by dramatically increasing the efficiency of water use and at the same time maintaining economic output, with the help of imported water, the construction of otherwise unimaginable storm-water storage reservoirs or the exploitation of difficult aquifers. The case of the plain of Hermosillo (Sonora, Mexico) has some similarities.

Examples of groundwater manangement under well-regulated circumstances will not be given since some attempts to do this failed due to the lack of the necessary administrative enforcement and man-power. In Mallorca, Tarragona Plain, SE Spain and the Canaries, the failure has not been complete since the imperfect rectrictions imposed by the Administration acted as a brake to the unrestricted development that probably had a significant role in avoiding the consequences of fast evolutions around the peak of demand.

Restrictions applied to only a small area may produce upsetting consequences. In the intensely exploited Middle Besós river alluvial plain, near Barcelona (Catalonia, NE Spain), to limit groundwater abstraction, new industrial wells were forbidden in the 100 m strip along the river (the distance of influence to public river water according to the old Spanish Water Law). This did not stop new wells outside these strips exploiting "private water", and development continued. In view of the inoperance of the rule, years later the limitation was lifted. As a consequence new wells were established inside the mentioned strips, where the alluvium is thicker. The increased drawdawn made the already existing wells unproductive, thus destroying existing investments and adding to existing social problems. Unpredictable changes in the regulations may thus create additional problems and economic losses.

6 CONCLUSIONS

Economic consequences (costs) of groundwater exploitation must be considered when computing expected benefits. Rules to control exploitation may reduce related costs but also reduce benefits and water use efficiency. It is difficult to decide between the two extreme situations, unrestricted and fully-controlled, the consequences being also highly dependent on other regulations and on the aquifer and water resources system. Intermediate solutions seem appropriate, but a well-conceived Water Plan and feed-back systems are necessary to introduce stability. Forecasted catastrophic failures, generally associated with unrestricted groundwater development, have not occurred in practice, though imperfect controls may have contributed to this. Water User's Associations seem important for the efficient use of scarce groundwater resources and reducing the weigh of water cost on local economy but a higher Administration is still needed to avoid excessive conservatism and the tendency to behave as an isolated entity, neglecting the social and economic links with neighbouring areas.

7 ACKNOWLEDGEMENTS

The author acknowledges the help received from the Secretariat of the Curso Internacional de Hidrología Subterránea, and the projects of the U.S. - Spain Joint Committee for Scientific and Technical Cooperation, CCA-8309-007 and CCA-8510-011. The comments received from Drs. A. Sánchez and A. Gurguí have been greatly appreciated.

REFERENCES

Albacete, M.; García-Lázaro, U.; Gutiérrez-Escudero, D. (1987): Estudio para la actualización hidrogeológica del sistema acuífero Ascoy-Sopalmo (Murcia). Hidrogeología y Recursos Hidráulicos. AEHS, Madrid, Vol. XII pp. 435-468.

Custodio, E. (1981). Sea water encroachment in the Llobregat and Besós areas, near Barcelona (Catalonia, Spain). Sea Water Intrusion Meeting. Intruded and Fossil Groundwater of Marine Origin, Uppsala. Rapporter och Meddelanden nr 27. Sveriges Geologiska Undersökning, pp. 120-152.

Custodio, E. (1985). Recàrrega, utilització i gestió d'aqüifers. Jornades Tècniques sobre Reutilització d'Aigües Urbanes. Castell-Platja d'Aro, Girona, Espanya, pp. 7-32.

Custodio, E.; Isamat, F.J.; Miralles, J.M. (1982). Twenty-five years of artificial groundwater recharge in Barcelona (Spain). Int. Symposium on Artificial Groundwater Recharge. Dortmund Deutscher Verband für Wasserwirtschaft und kulturbau e.V.-UNESCO. DVWK Bull. 11, Vol. 1 pp 171-192.

Custodio, E.; Bayó, A. (1986). Interactions between land-use and aquifer behaviour in the surroundings of Barcelona (Spain). 19th Congress of the International Association of Hydrogeologists. Karlovy Vary. Memories. Vol. XIX, part 1, "Norinár" Publishing House, 1987, pp. 90-100.

Custodio, E.; Iribar, V.; Manzano, M.; Bayó, A.; Galofré, A. (1986). Evolution of sea-water intrusion in the Llobregat delta. IX Salt Water Intrusion Meeting, Delft, pp. 133-146.

Ferret, J. (1983). Comunidades de usuarios de acuíferos subterráneos. Tecnología del Agua, nº 11, pp. 83-88, Barcelona.

López-García, L.; Amigó, E.; Custodio, E. (1981). Planteamiento y ajuste de un modelo matemático de simulación de la isla de Tenerife. Actas IV Asamblea Nacional de Geodesia y Geofísica. Zaragoza. Comisión Nacional de Geodesia y Geofísica, Madrid. Vol. III, pp. 1643-1673.

López-Camacho, B.; Gurguí, A. (1987): Modelo matemático de simulación del acuífero de la Llanura Manchega: aplicación al análisis de las alternativas de gestión. Hidrogeología y Recursos Hidráulicos, AEHS, Madrid, Vol. XII, pp. 379-392.

Llamas, M.R. (1984). Política hidráulica y génesis de mitos hidráulicos en España. Cimbra, nº 218, pp. 16-25, Madrid.

Llamas, M.R.; Sahuquillo, A.; Custodio, E. (1979). Groundwater policy in Spain. III World Congress on Water Resources, México. Int. Water Resources Association, Vol. III, pp. 3553-3561.

MAC-21 (1980). Proyecto de planificación y explotación de los recursos de agua de las Islas Canarias, proyecto CANHIDRO, actuación integrada en el Proyecto MAC-21. MOPU, Dirección General de Obras Hidráulicas. Tabla input-output. Las Palmas de Gran Canaria.

Miralles, J.M.; Cantó, J. (1984). Realimentación artificial de los acuíferos subterráneos de los deltas de los ríos Llobregat y Besós. Tecnología del Agua, nº 14, pp. 46-56, Barcelona.

MOP (1966). Estudio de los recursos hidráulicos totales de las cuencas de los ríos Besós y Bajo Llobregat. Comisaría de Aguas del Pirineo Oriental y Servicio Geológico de Obras Públicas, 4 Vols., Barcelona.

PHPO (1985). Modelo de simulación de los acuíferos del Bajo Llobregat. Plan Hidrológico del Pirineo Oriental. CAPO-CHPO. 3 Vols.

Sahuquillo, A. (1985). Groundwater in water resources planning: conjunctive use. Water International nº 10 pp. 57-63.

SPA-15 (1975). Estudio científico de los recursos hidráulicos de las Islas Canarias. Dirección General de Obras Hidráulicas. UNESCO, Madrid. 3 Vols.