COORDINATED TEMPORAL AQUIFER OVEREXPLOITATION AND EXTERNAL WATER TRANSFERS TO OPTIMIZE THE USE OF NATURAL WATER RESOURCES IN MARINA BAJA (ALICANTE PROVINCE, SPAIN)

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Abstract: A water resources simulation model has been applied in Marina Baja district, in Alicante province (Spain), as support to water management. In fact, a not planned, conjunctive use system for water supply, working for several decades, does exist in this area. This system will be modified when the Júcar-Vinalopó-Marina Baja transbasin diversion will be completely operative. A maximum annual amount of water to be transferred has been legally established. However the results of different alternatives (scenarios) simulated with the water resources management model show that scarce faults in the system supplies will be occur even though water transfers are lower than that legally assigned, using properly the water resources of the district, including temporal overexploitation of aquifers.

Keywords: Conjunctive use, Marina Baja, simulation models, water resources management.

Resumen: En la Marina Baja alicantina se ha establecido, esencialmente por iniciativa de los propios usuarios, un sistema ejemplar de utilización conjunta de aguas superficiales y subterráneas que va a ser modificado, en un futuro inmediato, por la llegada de aguas procedentes del trasvase Júcar-Vinalopó-Marina Baja. La cuantía del agua a trasvasar está especificada legalmente en una cantidad máxima anual. El uso de modelos de simulación de la gestión de recursos hídricos ha permitido estimar, para un período con todas las situaciones meteorológicas y para diferentes escenarios, que la optimización de los recursos propios del sistema, incluyendo la sobreexplotación temporal de los acuíferos, puede incrementar la efectividad de los trasvases aunque el volumen de éstos sea menor al establecido por la Administración.

Palabras clave: Gestión de recursos hídricos, Marina Baja, modelos de simulación, uso conjunto

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In some Spanish regions with limited water resources, users have exploited both underground and surface waters when they have had troubles in water supply and, of course, streams, reservoirs and aquifers have existed near demands. No specific conjunctive use policy has usually had in the long term planning of water resources among the objectives of Spanish Water Management Policy (Sánchez González and Murillo, 1997).

In Marina Baja district, in Alicante province, there is currently a system of conjunctive use of its water resources which works well since 1970 decade (Sahuquillo, 1983). That system (Fig. 1) is being modified according to the user's requirement and the socioeconomic development of the district. Water resources related conflicts are becoming frequent due to the characteristics of the temporal distribution of surface-water resources, the limitations of surface and underground water storage and exploitation, as well as the behavior of different types of demands (Castaño *et al.*, 2000a): urban and tourist demands (24 Mm^3/a), being Benidorm the most important, and irrigation demand (31 Mm^3/a).

In the near future, the system will have strong changes, because the Water Policy of Júcar Water-Resources Region foresees water transfers from Júcar River to supply urban and tourist demands, through Vinalopó Valley and Alicante District (Boletín Oficial del Estado, 1999). The assigned volume has been assessed in 10 Mm^3/a in the first stage. In fact, a 700 L/s of maximum capacity conduit exists between Alicante and Amadorio reservoir and occasional releases had been diverted, even though using Tagus-Segura Transbasin Diversion infrastructures.

The main components of the current system (Fig. 1) are two relatively small reservoirs. Guadalest reservoir has a maximum capacity about 13 Mm^3, and it stores water resources from the northwestern area of the district. The maximum capacity of Amadorio reservoir is about 16 Mm^3 and its catchment basin is in the southwestern zone of the district. Currently, these reservoirs are used mainly for urban supply even though they were built for irrigation.

Natural water resources of the reservoir basins, analyzed applying a modified version of Témez's rainfall-runoff model that considers two recession coefficients (Estrela, 1997), are irregular in time (Fig. 2). The mean inflow in Guadalest reservoir is 8 Mm^3/a, even though it can vary between 0.1 and 21 Mm^3/a (Castaño *et al.*,

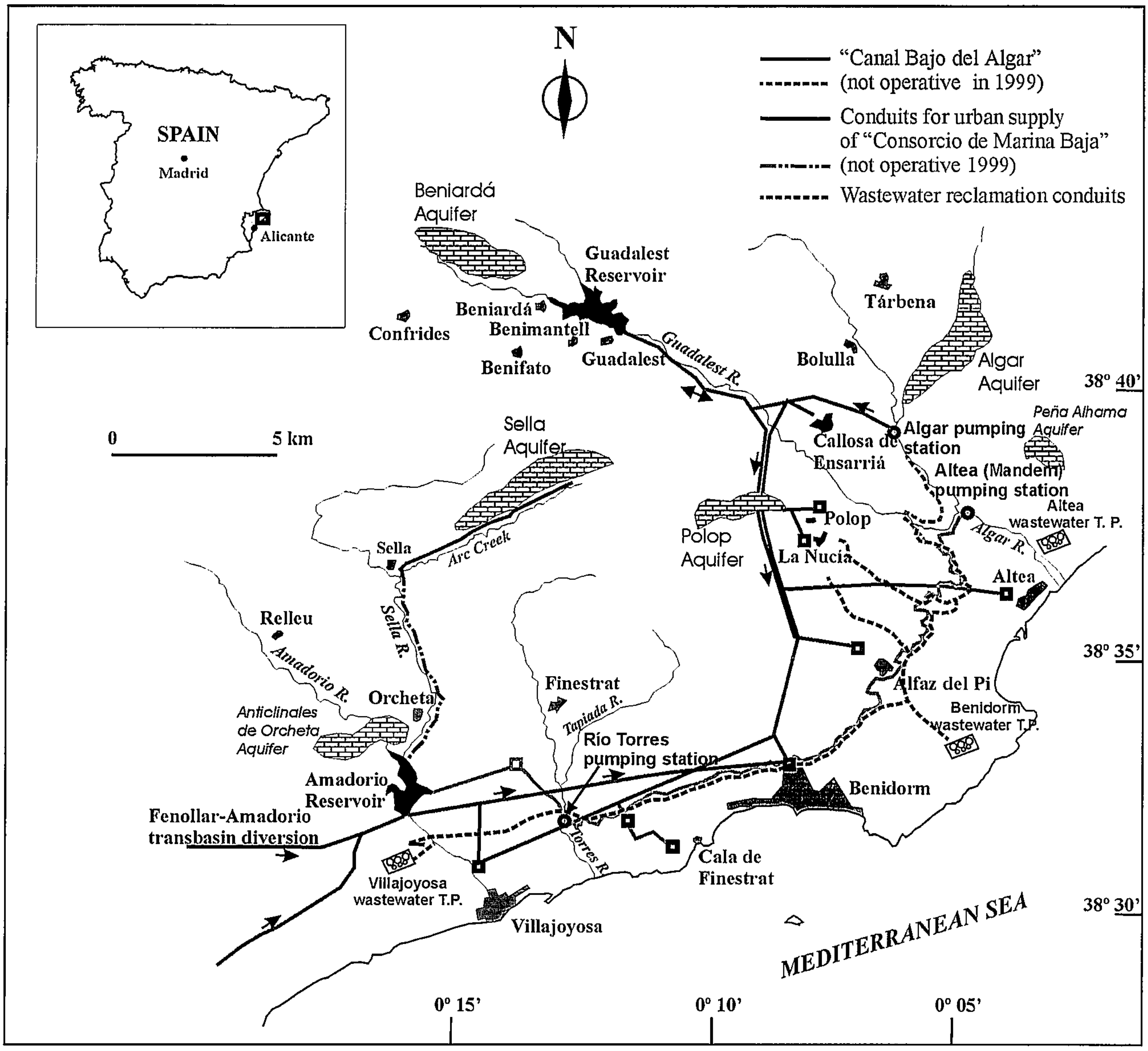

Figure 1.- Geographic situation of Marina Baja and main components of the integrated water resources system (modified from Castaño and Murillo, 2001).

2000a). The mean inflow in Amadorio reservoir is 6 Mm³/a, varying between 0.1 and 29 Mm³/a (Castaño *et al.*, 2000a). The streamflows in both basins (Fig. 2) are very irregular and usually simultaneous (Castaño *et al.*, 2000a).

There are two aquifers with an important role in water exploitation in the system since 1970 decade: Beniardá and Algar aquifers (Fig. 1). Castaño and Murillo (2001) have quantified the relative importance of their water resources in the supply system during some periods.

The Beniardá aquifer is upstream from Guadalest reservoir (Fig. 1), where the pumped water is stored. The Algar aquifer is the most important source of groundwater in Alicante province and is drained by several springs; their mean total discharge is 32 Mm³/a, but it varies (Fig. 2) between 2 and 81 Mm³/a (Castaño *et al.*, 2000a). These springs are used mainly for irrigation, but part of the flow is diverted for urban supply and stored in the Guadalest reservoir when the spring discharges exceed the supply needs. Moreover, in low-flow periods, Algar aquifer is pumped, by means of two wells, to the channel of Algar River and the water is used at the same way like the natural discharges are. Then, two subsystems can be defined for water supply: Algar-Guadalest and Amadorio.

The use of Beniardá and Algar abstractions as Guadalest reservoir inflow permits, since a longtime, a higher regularity in releases (Castaño *et al.*, 2000a), which are used mainly in urban and tourist supply (Fig. 3).

There are other aquifers in the system (Fig. 1) but they only supply a few specific areas. Only Polop aquifer, used in Polop and La Nucía, has some importance because of its central situation in the system and its possibilities for artificial recharge. In addition, some tests have been made to study the use of groundwater from Sella aquifer as inputs in Amadorio reservoir (Castaño *et al.*, 2000a).

The "Canal Bajo del Algar" channel interconnects both Algar-Guadalest and Amadorio subsystems, carrying surplus water from the first one to the second

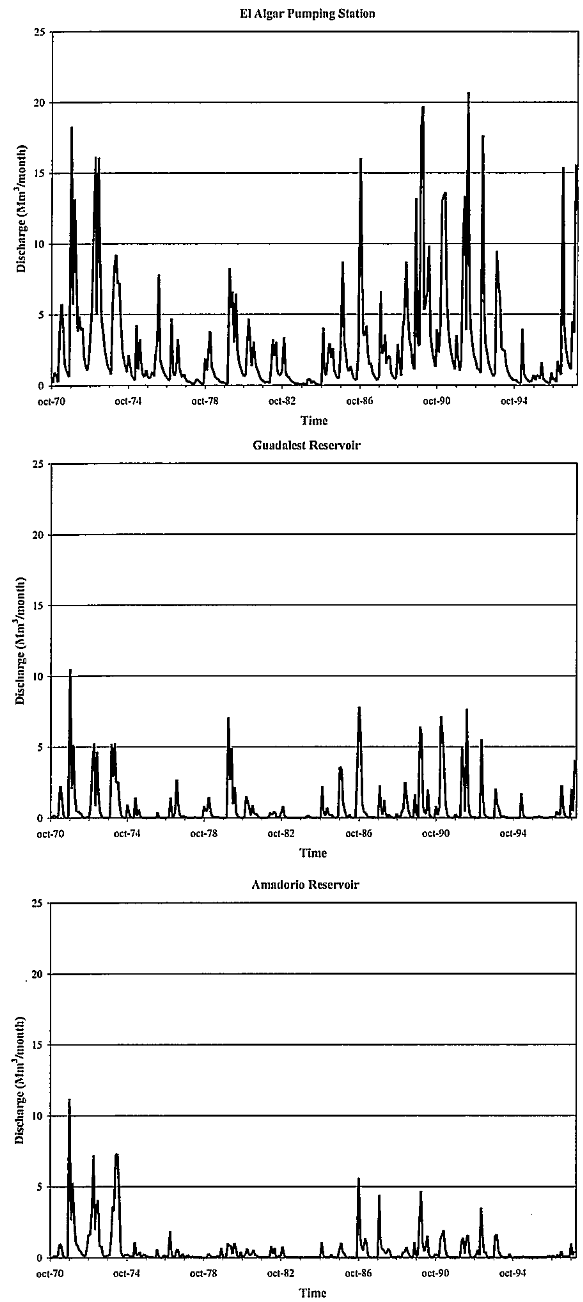

Figure 2.- Discharges of main drainage basins of Marina Baja district, obtained by means of the modified Temez's rainfall-runoff model.

one, where is stored (Fig. 1). Currently, this channel carries up to 600 L/s of water when it was built for 1500 L/s. Moreover, two ensembles of pipelines ("Conducción General de Guadalest" and "Conducción General de Amadorio") link reservoirs to the urban demands. The one from Guadalest supplies the largest number of demands of the district.

Finally, some of the farmers' associations use reclaimed treated urban wastewater while municipal suppliers use high quality water initially assigned to irrigation. Four wastewater treatment plants work in the general system (Fig.1). The average reclaimed water is different in each one: 75% of consumed water in Benidorm, Alfaz del Pi and Costa de Finestrat, 65% in Villajoyosa, 50% in Altea and 15% in La Nucía (Castaño *et al.*, 2000a).

Objective and method

The current water resources system of Marina Baja District will be deeply modified in the near future when superficial water from Júcar catchment basin arrives. A part of the supply supported by the water resources of the system will be substituted, mainly groundwater, by the transferred water, and demands will increase.

On the other hand, it is possible that the Júcar system can not supply as water as it is assigned to Marina Baja district, due to the hydrological characteristics of the area, where rainfall has irregular both spatial distribution and intensity. Then it will be necessary to pump the groundwater of the system again.

These periods can cause conflicts between users, specially if they do not come to an agreement or none forecast is made to take in account that situations.

The attempt to decide the allocation among various conflicting uses is one of the main objectives of water resources managers (Grigg and Labadie, 1978). This general objective has been applied to optimize the water resources of Marina Baja.

Thus, this paper tries to quantify the system response to the external water resource arrival. The minimal requirements of transferred water are calculated to obtain and acceptable water supply to the demands, using mainly the Marina Baja water resources. Then, it is necessary to consider changes in water sources, infrastructures and operating rules in the system. So, a management simulation model has been used as a tool to know the system response to those different alternatives (or scenarios).

The complex conjunctive use system of Marina Baja has been analyzed using SIMGES, a generalized water resources management simulation program that includes aquifers as system compounds.

Some different simulations, corresponding to different contexts in the system have been established. The alternatives have been simulated for 27-years (from 1971 water year to 1997 water year). The natural inflows in the system have been assessed for this period where most of usual hydrological situations (droughts and exceptional runoffs) are represented. Moreover, water transfers from Júcar catchment basin have been considered too, both uniform and variable, depending on the hydrological characteristics of the periods and the groundwater abstraction constrains.

Thus, it is possible to take into account many alternatives for the utilization of Marina Baja district water resources. The results could be used by decisions-makers to adopt the most beneficial actions for the district and to optimize its natural water resources, minimizing the use of transbasin water resources.

The SIMGES model

Numerical simulation of water resources systems is a tool widely used in long term planning and management of that systems. It permits to make the

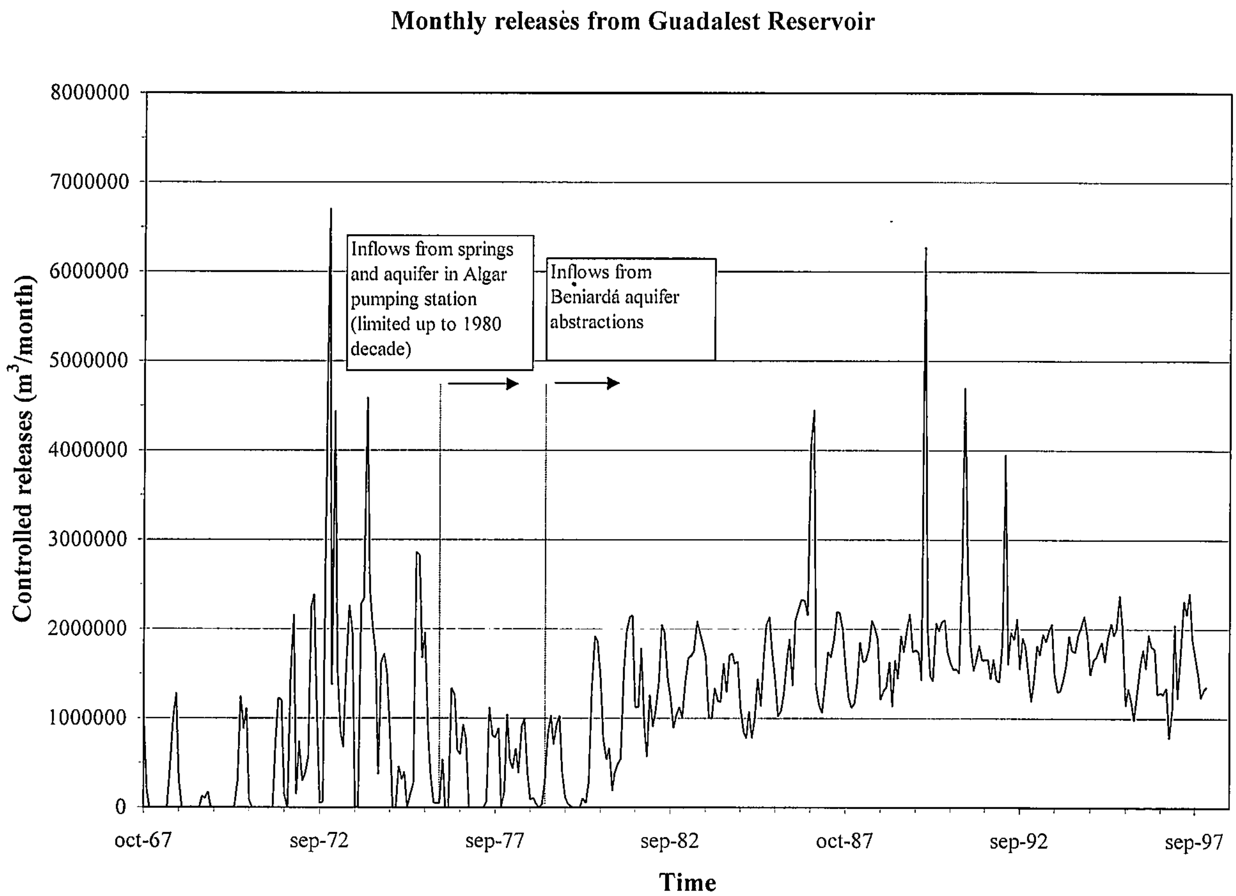

Figure 3.- Releases from Guadalest reservoir. Notice increase in regularity after groundwater became one of its inputs (modified from Castaño *et al.*, 2000b).

most convenient decisions about operating rules of the elements of the system (reservoirs, conduits groundwater abstractions), optimizing the use of water resources and increasing the supply reliability (Andreu, 1993, López García, 1993).

This aspect is very important in the water resources management in the coastal area of Marina Baja district because water managers and decision makers are looking for design a great number of possible scenarios to select those that increase the water reliability.

In Marina Baja district, temporal and spatial distribution of water resources, water use rights, the type and distribution of economical activities, the characteristics of infrastructures and water exploitation of both wells and springs, the changes of land and water uses, and the social and economical problems are aspects that support the use of water resources management models. These models must permit to simulate the complex quantitative and topologic relationships between the different compounds of the system, as well as the operating rules of the whole system.

The model used to simulate the water resources management in Marina Baja district is SIMGES (SIMulación de la GEStión). Its a generalized model, developed by the *Ingeniería Hidráulica y Medio Ambiente* Department of the *Universidad Politécnica de Valencia.* It can be applied in almost every type of basins or water resources systems with superficial or underground storage (reservoirs and aquifers), exploitation, conduits, demands, water reuse and artificial recharge elements (Andreu *et al.*, 2000; Andreu y Capilla, 1993).

That model is a module of a generalized decision-support system named AQUATOOL (Andreu *et al.*, 1993 and 1996), implemented within Microsoft Windows. SIMGES performs a simulation of the operational management for a given configuration of system compounds, time horizon and scenario, using different hydrological data and operating policies, on a monthly basis. It can be used to predict "what will happen" with the water resources of the system when each scenario is simulated. Moreover, SIMGES uses an optimization algorithm to deal with decision required each month by various elements, and produces the normal range of results, comprising simulated flows and storage levels for each element of the system, covering every month within the horizon (Andreu *et al.*, 1996).

Simulations of Marina Baja conjunctive use system

As said before, several scenarios of Marina Baja water resources system have been simulated using the SIMGES program.

The initial scenario -A0- considers the current situation of the water resources system (Fig. 4). The scenario A1 is similar to A0, but groundwater abstractions

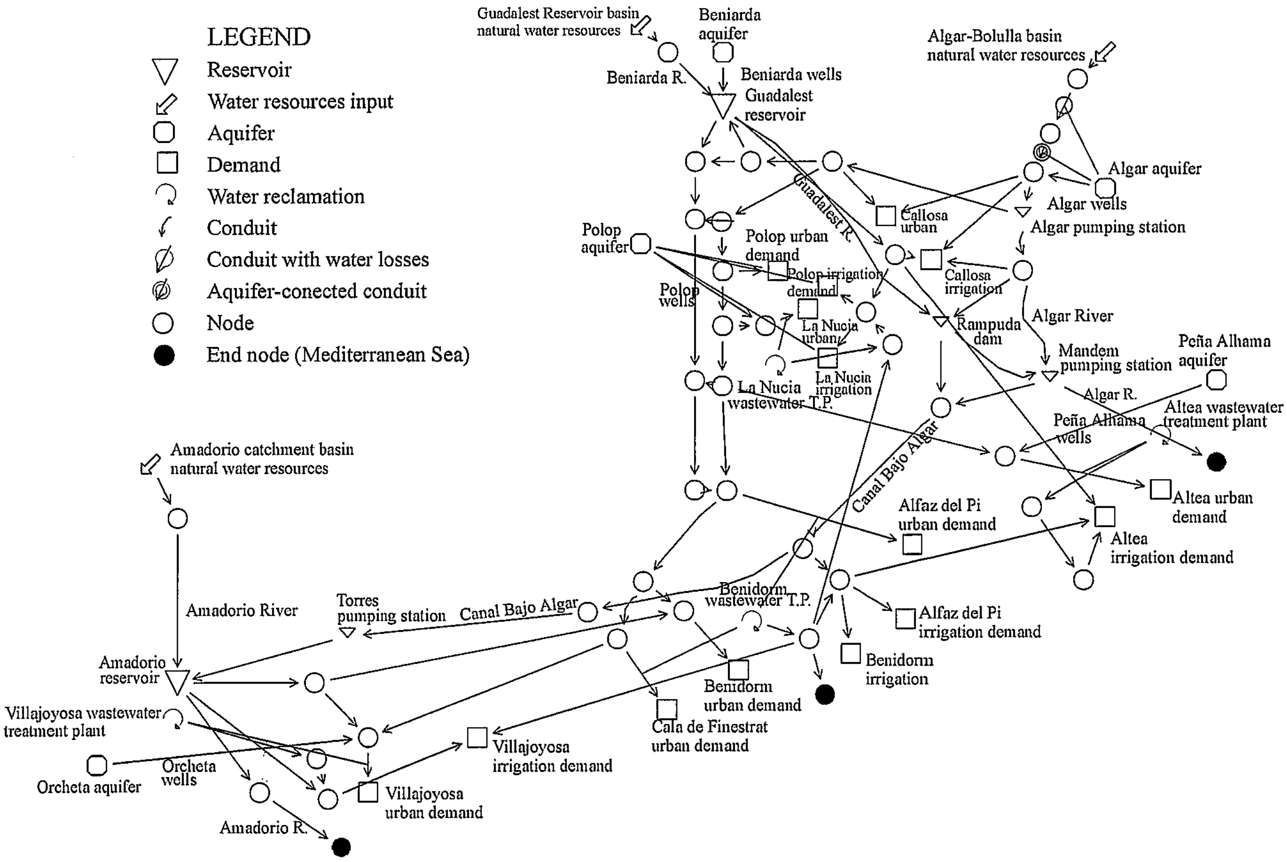

Figure 4.- Initial scenario (A0) in the simulation of water resources of Marina Baja district.

are limited according economical, technical and hydrogeological criteria. Next, several extreme changes of those scenarios have been modeled according to some possible future projects of the water managers and future demands (scenarios A1 to A8). These alternatives have been partially analyzed by Castaño *et al.* (2000 a, b). Table I shows the main characteristics of these simulations.

In all cases, the small capacity of Amadorio and Guadalest reservoirs and the irregular runoffs cause that the regulated, stored volumes in those reservoirs are scarce (Fig. 5). Water depletion will be very quick and long periods with no stored surface water would be common (Fig. 5). It would make necessary groundwater pumping to increase the water supply in the system.

Aquifer depletion in Marina Baja district would not cause severe impacts on streams of Algar-Guadalest subsystem. These streams are generally dry or are only used as conduits to distribute water to different users, usually farmers. Moreover, Algar springs can discharge again in rainy periods (Fig. 6) because of increase of stored underground water which is not used in supplies (Castaño *et al.*, 2000a).

Scenarios A4 and A5 consider water transfers. These transfers have not been calculated, but quantified taking into account the maximal capacity of pipeline from Júcar-Vinalopó-Marina Baja transbasin diversion (700 L/s). Demand increases in the near future has been considered in scenario A5. Those demands have been linked to the two supply subsystems, but specially to Amadorio one.

In both scenarios, the system responds (Table II and Fig. 7) with maximum storage in Amadorio reservoir (where the transferred water will be conveyed), minimum groundwater pumping and almost total reliability of water supply. However, the minimum use of groundwater causes loses of the Marina Baja water resources to Mediterranean Sea.

Scenario	Main characteristics
A0	Current situation
A1	A0 with constraints on groundwater pumping
A2	A1 + Improvements in infrastructures connecting main subsystem
A3	A1 + Sella aquifer pumping
A4	A1 + Constant water transfer from Júcar management system (22 Mm^3/a)
A5	A4 + New demands (9.5 Mm^3/a)
A6	A1 + Increase in wastewater reclamation (100% of urban supply)
A7	A1 + Saving water policy (10% of demands)
A8	A1 + Artificial recharge of Polop aquifer
A9	A2 + Variable water inputs + Saving water (5% of demands) + Increase in wastewater reuses (90% of urban supply)
A10	A9 + New demands (9.5 Mm^3/a)
A11	A10, but external water transfer limited to 10 Mm^3/a

Table I.- Main characteristics of the scenarios of the Marina Baja water resources system simulated using the SIMGES program.

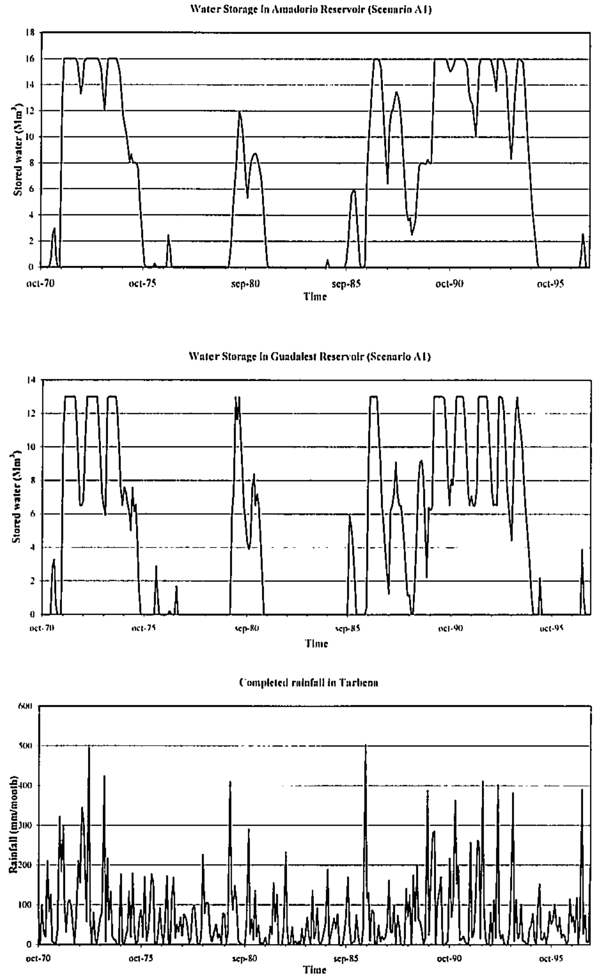

Figure 5.- Stored volume in Amadorio (above) and Guadalest (middle) reservoirs calculated in scenario A1, compared with recorded rainfall in Tárbena weather station.

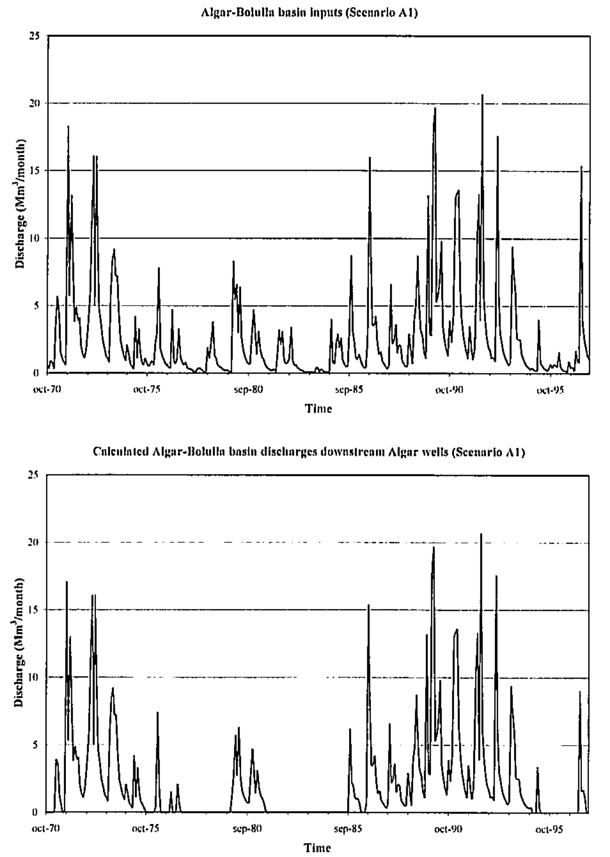

Figure 6.- Simulated decrease of Algar River discharges due to groundwater pumping in Algar aquifer

So, the previous alternatives have been partially combined in another one that could be more practical to increase the supply reliability of most of demands, optimizing the water resources of the district, using the Júcar water transfers only as support to the current conjunctive use system. The main characteristics of these additional scenarios (A9, A10 and A11) are described in Table I, where are compared with those above mentioned.

In short, in these three alternatives, water transfers have been simulated as groundwater withdrawal of a fictitious aquifer. In this case, and for the most of usual operating rules, SIMGES simulates groundwater pumping rates only when surface water resources are not enough to supply water over a specific percentage of demand (Andreu and Capilla, 1993). On the other hand, because of groundwater is simulated as directly delivered to demands having deficit, these pumping rates will not be calculated as storage in reservoirs. So the results about water storage in reservoirs, showed in Table II, are only partial. The main differences between those scenarios are described below.

The A9 scenario simulates a topology similar to current one, even though saving water policies and improvements of water distribution infrastructures have been considered. In the other hand, the amount of transferred water has been limited only by the maximum capacity of Alicante-Amadorio Reservoir conduit, as in A4 and A5 scenarios. The results would correspond with the optimum use of both surface and ground natural water resources of the system, being the external resources only the support for the water supply.

Scenario A10 is similar to A9, but a nearby Benidorm, 9.5 Mm^3/a, demand has been added. This demand increase is supposed in Spanish Water Policy in the near future (Boletín Oficial del Estado, 1999; Ministerio de Medio Ambiente, 2000).

Scenario A11 is similar to A10, but the volume of external transferred water has been limited to 10 Mm^3/a, the amount assigned by the above-mentioned Júcar Water-Resources Region Policy, in a first stage.

Results

The main results for the different simulations are summarized in Table II and Fig. 5. This one displays irrigation and urban supply reliability, and calculated water volume that reaches the final nodes of the model (Mediterranean Sea).

The most similar alternatives to the current situation (A0 and A1) show that temporal groundwater depletion, with the mean pumping rate near to 30% of total demand, is necessary to get a suitable water supply in the district. In fact, if Algar and Beniardá aquifers are not pumped the system faults about 30% of months and volumetric reliability is only 80% of demand. Then, groundwater acquires high weight in the real system (Fig. 3). From 1996 to 1998, Castaño and Murillo (2001) assess that groundwater was about 90% of the water resources stored in Guadalest reservoir, considering Algar River baseflow as groundwater too.

In these simulations (A0 and A1), groundwater withdrawal affects only temporally to surface water discharges, especially when several consecutive critical years occur. In rainy periods, increase of recharge and pumping rate reduction lead to aquifer recovery. This event has actually occurred several times since wells are used in the conjunctive use system, and has been simulated (Fig. 6) in each scenario.

Urban demands with widespread water sources (surface and underground water, connected to both Amadorio and Guadalest subsystem, etc.) have higher supply reliabilities. However, even though Guadalest subsystem has more water resources (higher rainfall and runoff, Algar and Beniardá wells), it is extremely vulnerable to supply faults because of numerous demands depend on its distribution infrastructure that extends to nearby Amadorio reservoir (Fig. 1).

Some of the simulated alternatives yield almost complete supply reliability (see A4 and A5 in Fig. 7). As said previously, they consider high rates of water transfer from Júcar River to Amadorio reservoir. The results of these simulations show considerable loss in surface water resources to Mediterranean Sea and small requirement in groundwater pumping (Table II), thus aquifers and reservoirs would regulate scarce district water resources.

Other alternatives with partial operational modifications do not yield a significant increase of the supply reliability, which is very high already.

Thus, the simulated scenario A2, which considers improvements in hydraulic infrastructures, yields higher urban supply reliability than alternative A0. Yet, similar results have been reached increasing both wastewater reuse (alternative A6) and water saving (A7). The simultaneity in natural inflows in main regulation elements (reservoirs and El Algar pumping station, Fig. 2) does not allow increase the storage of water in the system. In the two last mentioned alternatives (A6 and A7) deficits of irrigation demands decrease as the reliability grows.

Pumping Sella aquifer to store the groundwater abstractions in Amadorio reservoir (alternative A3) only increases water resources regulation of Amadorio subsystem but not the water resources of the whole system.

Moreover, artificial recharge of Polop aquifer when inflows exceed storage capacity of Guadalest reservoir (alternative A8) does not cause that reliability are higher because water could only be injected in periods of maximum inflows, when groundwater stored in the aquifer is at its maximum too.

Surely, the most adequate simulated alternative for a high supply reliability with an optimal proficiency of the own water resources of Marina Baja district (Table II and Fig. 7) is that considering mainly water saving policies and the use of other alternative sources for

Scenario	Total demand (Mm^3/a)	Mean deficit (Mm^3/a)	Months with empty reservoir (%) Amadorio res.	Months with empty reservoir (%) Guadalest res.	Mean pumping rates (Mm^3/a)	Mean water outputs (Mm^3/a)	Mean external water transfer (Mm^3/a)
A0	55.3	0.93	43.2	46.9	14.54	14.71	0
A1	55.3	2.44	39.2	43.5	11.84	15.58	0
A2	55.3	2.15	37.0	42.6	11.36	15.32	0
A3	55.3	2.08	39.5	43.5	12.12	15.59	0
A4	55.3	0.00	0.0	19.8	3.15	28.19	22
A5	64.8	0.08	4.6	30.2	5.52	21.08	22
A6	55.3	0.90	25.9	35.2	7.75	18.63	0
A7	49.8	1.15	32.4	37.7	9.12	16.86	0
A8	55.3	2.43	39.2	43.5	11.84	14.40	0
A9	52.5	0.07	27.5	35.2	5.82	18.43	3
A10	62.0	0.09	41.4	44.4	9.14	14.66	6
A11	62.0	1.46	41.0	44.8	9.79	14.66	4

Table II.- Main results of the management simulations of Marina Baja district water resources system.

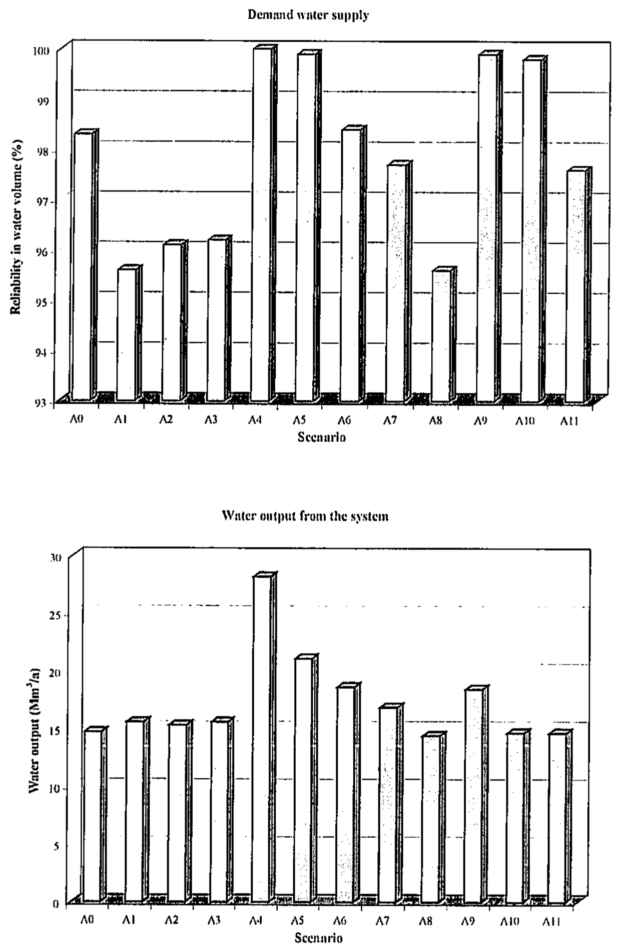

Figure 7.- Summarized results of irrigation and urban supply reliability and output of water resources towards Mediterranean Sea.

irrigation, such as the wastewater reuse or the pumping of low quality water from some aquifers for other urban uses different to human consumption (scenario A9). External water conveyances are reduced to few periods, but the monthly-required volumes reach relatively high values (Table III and Fig. 8). Moreover artificial recharge, planned groundwater resources use and maintenance of currently deteriorated infrastructures will increase the system efficiency. External water is conveyed to Amadorio subsystem, which will improve water supply in the southwestern area. Then, the water from Algar-Guadalest subsystem, that supplied the southwestern zone of the district, could be used in the zone only connect to Guadalest reservoir. So the northern area will improve its water supply too.

Both surface and underground water requirements will increase heavily (Table II) if future demand grows near 10 Mm^3/a, as it has been assumed in scenario A10. In this simulation, the overall supply reliability decrease, but only lightly (Fig. 7), due to external water conveyance is limited by conduit capacity and groundwater withdrawal is also limited by pump and well characteristics. Mean calculated water transfer requirements (Table III) are lower than those assigned by Júcar Water-Resources Region Policy (Boletín Oficial del Estado, 1999). However, if long dry periods occur, water requirements are calculated equal to maximum capacity of Júcar-Vinalopó-Marina Baja conduit (Table III and Fig. 8).

In scenario A11, transferred water releases can also reach 700 L/s, even though they were limited to 10 Mm^3/a. Then, supply reliability decreases and deficit is not completely compensated by groundwater pumping, because this is limited. Incoming water requirements (Fig. 8) show very high peaks, similar to those calculated in scenarios A9 and A10. The volumetric reliability decrease is scarce, since mean deficit is lower than 1.5 Mm^3/a (Table II), which is 3% lower than that assessed in alternative A10. However, monthly water supply faults increase between 5% and 10%. Considering that demands are strongly seasonal, the most important are tourist, and the faults will occur mainly in summertime, supply faults can mean serious problems for the economic development of the district

However, any of the three last mentioned alternatives (A9, A10 and A11) shows that regulating the natural water resources of the district is possible supply totally the demand around the 50% of simulated period, even though demands increase near 20% (Table III). So, the current conjunctive use system optimizes the water resources consumption, at least from the quantitative point of view.

In spite of that excellent reliability of the system, the amount of water resources mainly depends on the climatic characteristics of the district, due to the scarce storage capacity that aquifers and, specially, reservoirs presents. Rainfall use to be irregular and intense (Fig. 6 and 8), and the natural discharges are too (Castaño *et al.*, 2000a). So, external water is necessary when long dry periods occur (Fig. 8). The transferred water requirements are very irregular and complementary to rainy periods. The transfers would reach peaks equal to maximum capacity of conduits, especially when rainfall is scarce (Fig. 8). Regular in time water incoming to be stored could compensate these peaks, but small capacities of reservoirs and bad aquifer characteristics would make difficult this operation.

Finally, when droughts will be long and generalized, they can affect the Júcar catchment basin and the water stored in the regulation infrastructures. So, the releases towards Marina Baja can decrease or cut off. Then, natural water resources, regulated by means of

Scenario	Total demand (Mm^3/a)	Years with no needs of water transfers	Maximum transfer (Mm^3/a)	Years with calculated transfers higher or equal to 10 Mm^3/a	Mean annual water transfer (Mm^3/a)	Mean pumping rates (Mm^3/a)
A9	52.3	16 (60%)	14.72	3 (12%)	2.69	5.82
A10	62.0	13 (49%)	21.78	7 (26%)	5.95	9.14
A11	62.0	13 (49%)	10.00	6 (23%)	4.28	9.79

Table III.- Characteristics of external water requirement calculated by SIMGES in scenarios A9, A10 and A11

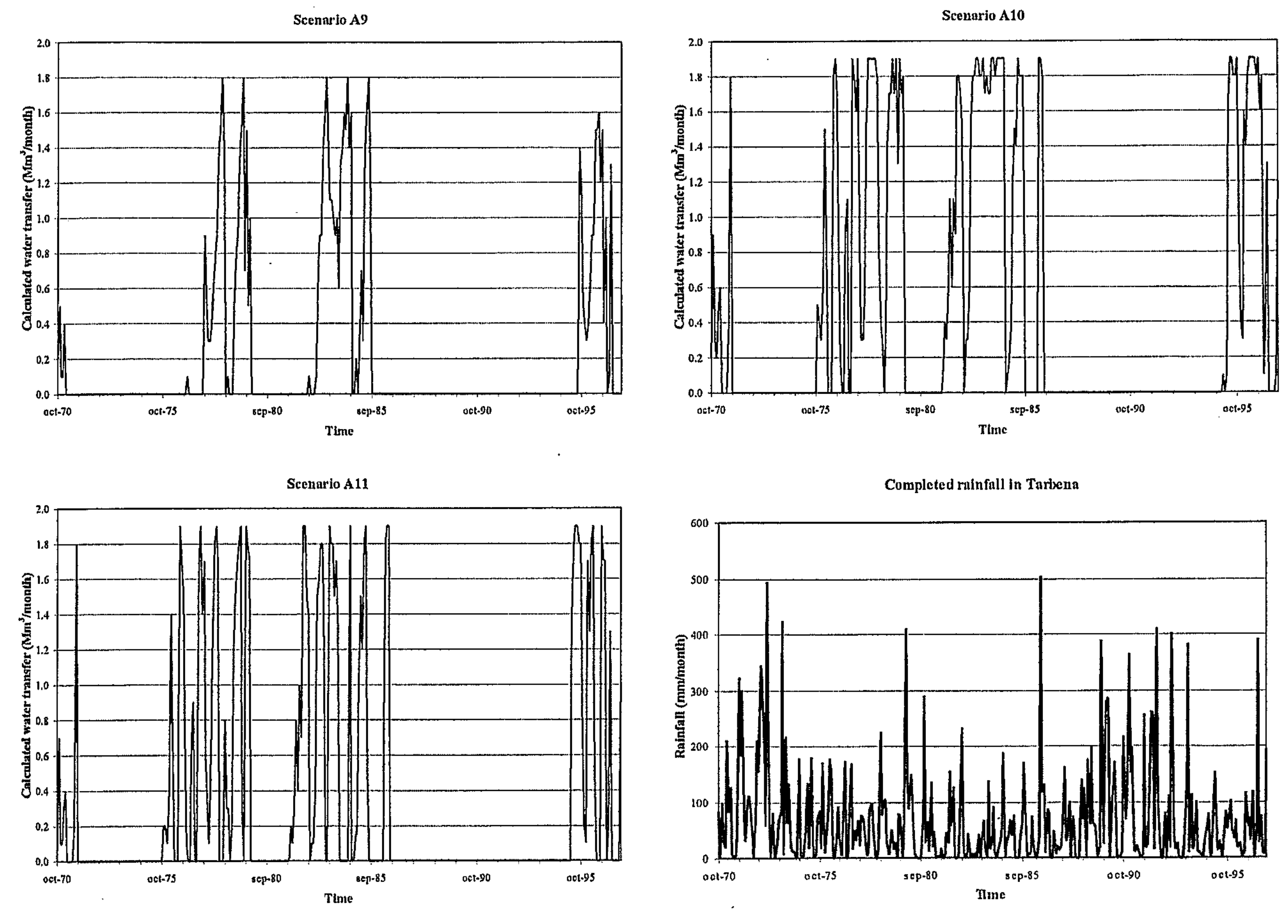

Figure 8.- Calculated requirement of external water resources in Marina Baja supply system, considering current situation with improvement (A9), water transfers limited by pipe capacity (A10), and water transfer limited to 10 Mm^3/a (A11). Comparison with rainfall in Tárbena weather station.

groundwater abstractions, would be absolutely necessary to supply an important percentage of the water requirements of Marina Baja district.

Conclusions

Several conclusions can be extracted from the above-described water-resources simulations realized with SIMGES program. Some of them can be emphasized, and are described below.

Thus, in the current situation, the conjunctive use scheme of Marina Baja district (Alicante province) is appropriate for water requirement of the area. If supply faults lower than 5% are allowed, supply can be considered complete. However, the high variability of both rainfall and runoff and the scarce artificial regulation of water resources can originate high peaks of water-supply deficit.

Temporal aquifer overexploitation supporting water supply for the demands does not cause severe problems in the whole water system, because of aquifers can recuperate after short rainy periods.

Using external water, by means of transbasin diversions from Júcar basin, as support for water supply, will increase the artificial regulation of water resources, especially in the area depending on Amadorio reservoir.

These water transfers will be absolutely necessary if demands increase considerably, as Spanish Water Policy foresees, due to the scarce ability of small reservoirs to regulate the natural resources, and the technical limitations of groundwater withdrawal.

The mean amount of external water requirements is relatively scarce (6 Mm^3/a, if the component is only limited by the capacity of conduits). However, transferred volumes should reach high peaks (near 22 Mm^3/a) if long droughts occur. Water transfer assignment is limited to 10 Mm^3/a, so the system reliability will decrease, because both volume and monthly deficits will raise.

If droughts are coincident in Marina Baja district and Júcar River basin, water transfers are not sure, unless Júcar regulation infrastructures permit regulate water resources of several years. Then groundwater will become the indispensable water source during these dry periods, and always in the Algar-Guadalest subsystem.

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References

Andreu, J. (1993): Análisis de sistemas y modelación. En: *Conceptos y métodos para la planificación hidrológica* (Andreu, J. Ed.). CIMNE, Barcelona, 25-33.

Andreu, J. y Capilla J. (1993): El modelo de gestión de cuencas SIMGES. En: *Conceptos y métodos para la planificación hidrológica* (Andreu, J. Ed.). CIMNE, Barcelona, 298-321.

Andreu, J., Capilla, J. y Sanchis, E. (1993): Sistema Soporte de Decisión basado en ordenador para planificación de sistemas complejos de recursos hídricos. En: *Conceptos y métodos para la planificación hidrológica* (Andreu, J. Ed.). CIMNE, Barcelona, 371-391.

Andreu, J., Capilla, J. y Sanchís, E. (1996): AQUATOOL, a generalized decision-support system for water-resources planning and operational management. *Journal of Hydrology*, 177: 269-291.

Andreu, J., Capilla, J. y Solera, A. (2000): *Modelo SIMGES de simulación de la gestión de recursos hídricos, incluyendo utilización conjunta. Manual del usuario. Versión 2.2*. Universidad Politécnica de Valencia. Valencia. 94 pp.

Boletín Oficial del Estado (BOE) (1999): Orden de 13 de agosto sobre Normativa del Plan Hidrológico de la Cuenca del Júcar. *BOE núm. 205, de 27 de agosto.*

Castaño, S., Murillo, J.M. y Rodríguez Hernández, L. (2000a): Establecimiento de reglas de operación y recomendaciones de gestión de los recursos hídricos de la Marina Baja de Alicante mediante el empleo de un modelo matemático de simulación conjunta. *Boletín Geológico y Minero*, 111, 95-118.

Castaño, S., Murillo, J.M. y Rodríguez Hernández, L. (2000b): Aplicación de un modelo matemático para la simulación de la gestión conjunta de recursos hídricos en la Marina Baja (Alicante). *Geotemas*, 1(2): 55-58.

Castaño, S. y Murillo, J.M. (2001): Papel de los recursos hídricos subterráneos en el esquema general de suministro conjunto de agua a la comarca de la Marina Baja (Alicante). *Boletín Geológico y Minero*, 112: 77-94.

Estrela, T. (1997): Formulación teórica del Modelo Témez. Calibración de parámetros. In: *Master en Hidrología General y Aplicada del CEDEX. Área de Hidrología Superficial II*, tomo III, 18 p.

Grigg, N.S. y Labadie, J.W. (1978): Introduction. In: *Management of water resources: A system approach. 30 English lectures*, Colorado State University, Fort Collins, 1.1-1.10.

López García, J. (1993): Simulación de sistemas de recursos hidráulicos. In: *Conceptos y métodos para la planificación hidrológica* (Andreu, J. Ed.). CIMNE, Barcelona, 126-135.

Ministerio de Medio Ambiente (2000): *Plan Hidrológico Nacional. Análisis de sistemas hidráulicos*. Ministerio de Medio Ambiente, Madrid, 390 p.

Sahuquillo, A. (1983): La utilización conjunta de aguas superficiales y subterráneas como paliativo de la sequía. *Hidrogeología y Recursos Hidráulicos*, 7: 253-280.

Sánchez González, A. y Murillo, J.M. (1997): *Integración de los acuíferos en los sistemas de explotación*, Servicio de Publicaciones del Ministerio de Medio Ambiente, Madrid, 41 p.

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