3.2.8 S-ClimWaRe

Introduction

Scope of prototype

The Mediterranean area is dependent on the state of the water resources for assuming several activities such as agriculture, domestic supply and leisure activities. In the last decades, important investments have been made to manage interannual climate variability (construction of dams, intense exploitation of aquifers, etc.) and to adapt activities to drought periods (restrictions rules, control of water demand, etc.). New solutions, such as the use of seasonal predictions, are now useful to cope with future challenges in water management in this area: increasing population, climate change, environmental objectives, economic efficiency…

In the water sector-specific case-study and prototype, the use of the seasonal predictions would be tested for some key applications in water resource management:

- domestic water demand forecast
- water resources availability forecast
- dam management (operative rules)
- rules concerning the distribution of the resources in the river basin (restriction, ecological flow allowance…).

Scope of vulnerability analysis

Water management problems comprise many different tasks and aspects covering diverse sectors. The number of critical situations caused or influenced by climate is therefore manifold and probably difficult to identify and analyse completely. Thus, this vulnerability analysis focuses on the problem of water supply management i.e. specifically reservoir management which implies controlling of rates of water inflow and release considering diverse interests, safety issues and user needs.

System of concern

The river basins are the logical physical boundaries of the system. Nevertheless, some hazards may affect larger area. As an example, drought could persist over months or years; it can affect large areas and may have serious environmental, social and economic impacts (Horion, Carrao et al. 2012).

The river basin agencies are the key organization involved in the management of the resources according to the water framework directive. Their work is done in collaboration with the state (MAGRAMA in Spain) and European agencies, and with the local stakeholder in the river basin.

The river basins are also the main operational boundaries of the system, including sub-systems at a lower administrative level. At this lower level, Spanish regulation ("Reglamento de la Planificación Hidrológica") define the water operating system ("sistema de explotación de recursos") as a surface water bodies and groundwater, water infrastructures and water use rules to comply with the environmental objectives. In these systems, the rules of management are defined and applied in collaboration with the local stakeholders and users (e.g. representative of agriculture, hydropower, water supply…).

At the upper level (national administration), some links also exist between the river basins such as water transfer, or supervision of the state agency (MAGRAMA) for the river basins shared between various autonomous communities in Spain. Currently, Spain has 25 river basin districts, out of which 6 are international sharing water courses with France to the northeast and Portugal to the west (EC 2015).

Critical situations

The general task of water managers is to provide water supply to cover respective demand of different stakeholders and users within a specific basin. This relative straightforward task is complicated by the plurality and diversity of users like industry, energy production, agriculture, inland waterway transport, tourism and especially municipal use of water (drinking water and wastewater) which all have individual needs especially with respect to volume, purpose of use and timing (Noel 2009). Since 2000 in the context of the Water Framework Directive this rather *resource based approach* is shifting towards a new *ecosystem approach* on a basin level (Integrated Water Resource Management). Besides the issue of water supply managers also have to consider regulations of natural protection to preserve water resources and aquatic environments and integrate different stakeholders (institutions, economic services, natural hazard management).Thus water management does not only imply the managing of available water supplies (quantity) and its related hazards like droughts and floods but also the preservation of flow rates, quality and feedbacks from affected systems (Atwi and Arrojo 2007).

To predict future water availability in a reasonable way water managers require a firm understanding of the natural water cycle and the variability of water resources at different scales within a catchment. A common critical method of managing hydrological variability is the use of storage reservoirs. Reservoirs provide a significant although limited opportunity to control water supplies by storing water at times where water availability is greater than the demand for seasons with potential water scarcity. Reservoir design is tightly related and based on historical streamflow, current water needs and projections for future water needs as well as future water availability. Thus, assuming stationarity, prevalent water supply systems do meet the need of current and near future water use. Challenges may occur with respect to the reliability (buffering of variability) and the sustainability (future reliability) of such systems (Brown, Baroang et al. 2010).

Hazard: With respect to water supply the hazard is related to the water availability relative to the demand in terms of volume and especially timing. The Ebro Basin in Spain was the first river basins in Spain considered into the EUPORIAS project (Ebro Basin agency entered as a stakeholder from the beginning of the project); later other basins were also considered in the study (Tagus, Douro, etc.). Accordingly, the situation of the Ebro Basin is analysed more in details in the following sections and most of the analysis would be representative of the other basins in Spain (with some limitations). The basin drains an area of about 85,000km^2 which comprises 347 main rivers. The annual water flow varies significantly between summer and winter and can fluctuate from 3,811 hm^3 to 26,134 hm^3 per year causing a rise of water levels of 7-9m above average during the heavy rain season in fall and spring (Water2Adapt 2010). Water availability is also unevenly distributed in space and time: at which the head of the tributaries in the Pyrenees receives much more rainfall (~3,800 mm/year) than the central river valley (100 mm/year) where the main economic activities are located. Inter-annual variability is also significant and ranges between 800 mm and 450 mm

in wet and dry years (Omedas, Galvan et al. 2011). Ebro River and its tributaries are managed by about 187 dams which have a total capacity of about 60% of the total mean annual runoff (Batallaa, Gómezb et al. 2004) which is about 7,500 hm^3 in total and thus more than the half of the mean annual available water (Iglesias, Cancelliere et al. 2007, Omedas, Galvan et al. 2011). Mean available water resources are estimated at around 14,600hm^3 per year from which around 8,400m^3 are extracted. Agriculture claims the greatest demand with around 7,700hm^3 (92%) and the rest is used for industry, energy, urban use and for transfers to other basins in Spain. Future demands are expected to increase by 30% until 2027 while water availability is expected to decrease by 10% (2040) to 30% (2100) (Kahil and Albiac 2014).

The major problem is to provide sufficient water to cover the demand during summer (peak water demand, mainly for irrigation purpose) and during one year or several consecutive years of below normal inflows (dry years). Thresholds for high- and low-flows used in decision-making are generally static, but some little adjustments could be done during the year for exceptional situations (very high inflow, drought, etc.). These rules have been elaborated based on historical hydrological records and the analysis of the consequences that extreme events may have on the system.

Decision-making processes: Water and reservoir management on the basin scale is strongly influenced by national (e.g. National Hydrological Plan), European (e.g. Water Framework Directive) and international laws and directives which regulating water distribution and quality issues, dam safety and emergency management, ecosystem preservation and flood and drought management (prioritization of water allocation) (Santaengracia and Argüello 2012, Castillo-Rodríguez, Morales-Torres et al. 2015). This has fundamental consequences for decision-making processes on management of multi-purpose reservoirs: water storage for drought management and hydropower rather demands the exhaustion of the storage capacity. In contrast, flood management requires a certain storage buffer and regulations on water quality require a minimum reserve within the reservoir. Ecological and health issues require a minimum flow of water to avoid eutrophication and sedimentation of the reservoir and alteration of downstream aquatic ecosystems. Flow regulation is also desired for flood protection and the prevention of erosion (Horne, Dracup et al. 2003, Palau 2006, López-Moreno, Vicente-Serrano et al. 2009).

Since the main purpose of the reservoir in Ebro basin is irrigation (~90% of total water demand) the focus of reservoir management is to reach maximum volume shortly before the beginning of the hot season when irrigation is required. The main filling periods in Spain are thus during the rainy periods in autumn and spring (October until April/May). The velocity of infilling largely depends on the rainfall regime and especially on the seasonality and intensity of flood events. Especially in Mediterranean regions a large proportion of the annual discharge concentrates on a few events which highlight the importance of flood events. Floods in October and November are often used to quickly increase the stored volume. Infilling is then partly paused for safety reasons and the definite infilling occurs in spring (López-Moreno, Beguería et al. 2004). The sensitivity of the reservoirs is dependent on their storage capacity: small dams with limited capacity are filled and emptied in a yearly cycle and are thus sensitive to intra-annual variability of discharge. In contrast, larger dams with a high storage capacity can regulate climate intra-annual variability but are sensitive to successive years of drought.These characteristics of reservoir management explains the

uncertainty of inflow control and flood-risk assessments to meet dam safety regulations which requires high flexibility in decision-making.

For the Ebro-basin decision-making on the water needs for the coming season happen in general meetings with River Basin Agencies and users in October and March (‘junta de explotación’). At the beginning of the hydrological year (October) the current situation (reserve in dam) will be analyzed, and the expected state for the next 6 months will be assessed. This prediction over the next months is commonly based on historical information only (e.g. historical inflows) and physically based climate forecast are not considered. As a result, the decision making process is directly connected to the current state of the system. In March there will be a look at the current state of water levels in reservoirs and the situation of snow reserves in the mountains. Decisions are made on water allowance for the coming irrigation period (April-October) which is mostly based on average resources from the past 10 years (pers. com. L. Pouget).

Under normal conditions, the Reservoir Releases Commission (Comisión de Desembalse, which is one member of the “*junta de explotación”* commented before) will meet in ordinary session and will define some actions relative to reserve management, onset of right exchanging centres, revision of ecological flows and ground water abstraction and definition of precautionary water allocation schemes. All these measures affect farmers, hydropower units, environment, urban users and others. The commission meets in October to decide upon the proper filling level of the reservoirs during the wet season and at the beginning of spring to decide upon the allocation of reservoir releases during the dry season. The commission’s recommendations must take into account the water supplies expected to be available and the licenses held by water users (Bhat and Blomquist 2004).

Drought indices are calculated on a monthly basis during the dry season (as defined in the Sub-basin Management plan) which is used to take measures for drought management (restrictions, emergency infrastructure operation, increasing monitoring and surveillance, minimum ecological flow discharges, etc.). In contrast, intense precipitation events are anticipated especially between October and March on a 48 hour time scale (minimum) to assess flood volumes and improve flood management and respective dam operations on the basin scale (CHE 2014; pers. com. L. Pouget).

Critical situation: the critical situations related to decision-making processes for reservoir management in the context of balancing supply and demand can be defined as follows:

A critical situation arises when a high variable discharge regime occurs during the rainy season (October-May) as this challenges the ability to balance the need for maximizing the reservoir capacity until June and buffering unexpected flood events between January-April.

Buffer system characteristics

For water management issues in context of reservoir management the availability of water in form of discharge is the attribute of concern. Water managers and users get a problem when there is a “prolonged period with below-normal water availability in rivers and streams, and lakes or groundwater bodies due to natural causes” (VanLanen, Wanders et al. 2013 p.1716) thus, a hydrological drought. Hydrological droughts evolve slowly and are due to periods of low precipitation combined with high evaporation losses which causes soil

moisture deficits and subsequently reduces groundwater recharge and head and eventually lowers stream flows (Maybank, Bonsal et al. 1995). The area affected by droughts is primarily climate driven whereas local variability is influenced by characteristics of the terrestrial system. Hydrological storage or a combination of catchment characteristics which relate to catchment storage and release (e.g. land use and geology) is the most important factor controlling drought propagation and causing lag times between a meteorological drought and hydrological drought and its spatial characteristics (Tallaksen, Hisdal et al. 2009, VanLoon and Laaha 2014). The monitoring of hydrological reservoirs within a catchment is also a central element of the Spanish Drought Management Plan (Monreal and Amelin 2008).

In contrast, the occurrence of flood events is much more sensitive to changes in hydrological reservoirs. For flash floods the soil do not even need to be saturated. High magnitude rainfall events may exceed the infiltration rate of the soil, causing surface runoff and thus provoke local flooding despite rather dry soil conditions. Also snowmelt floods and rain-on-snow floods are often dominated by temperature which controls the activation and the draining of the respective hydrological storage (Merz and Blöschl 2003).

Dams and reservoirs can also be considered as hydrological storages and thus as an additional buffers. However, these storages should be considered as different buffer systems, since this storage type is controllable and stored water is available at discretion. The infilling of these storage types is dependent on the discharge of the catchment draining the area uphill of the reservoir but the release rate can be controlled by decision-makers.

Critical climate conditions and climate information

Critical climate conditions

The relation between discharge and rainfall is strongly dependent on catchment characteristics especially the state of hydrological reservoirs. The development of hydrological droughts is a slow process and not only dependent on periods of low rainfall but also on temperatures and evapotranspiration potentials. Required time-scales over which precipitation events need to be below average or even lacking to provoke hydrological droughts are in general seasonal for fast responding catchments and may be inter-annual in catchments with large hydrological storages (vanLanen and Tallaksen 2007). For the Ebro Basin the response of monthly runoff to precedent climate conditions (represented by the standardized precipitation evapotranspiration index (SPEI)) was analysed for different catchments of varying size. Three main sub-basin groups could be identified with respect to their streamflow response to SPEI at different time scales: the unregulated head-water areas are sensitive to time-scales of 2-4 months. In contrast, sub-basins which are groundwater controlled do have response times from 10-20 months and sub-basins at the lower sectors of the Ebro Basin which receive flows from the other sub-basins and where dam regulation play a significant role have response times from 6-10 months (López-Moreno, Vicente-Serrano et al. 2013).

Critical climate conditions for floods are short-term (see above). However, since flood management with respect to dam safety is a short-term event with short-term decision-making this problem is not further considered in this analysis.

Critical climate conditions are below-average precipitation during the year combined with above-average temperatures. Furthermore, extreme high rainfall events during and especially at the end of the rainy season (October-May).

Climate information

To assess the potential inflow within the filling season information on total rainfall and temperature from October to March is desired. Thus the demand is for a 6 month-forecast available at October. In March another 6-month forecast is required to assess the demand for the hot season and assess the final requirements on infill during spring. Consequently, year-round climate information is desired portioned to infill-season and release-season which also define the timing of decision-making.

To assess flood events during winter information on total water availability is sufficient however information on the distribution (magnitude-frequency) would be desired to be able to cope with individual events especially at the end of the filling season when reservoirs are rather full.

Vulnerability attributes

Criticality of the problem: water availability in a drought-prone region is basically a very critical factor and thus related decision-making processes are of general criticality. However, decision-makers which have to decide on water resources and their allocation do rather have a risk-averse attitude: uncertainties on water availability are countered by worst-case hypotheses to avoid risky (irreversible) decisions of users (e.g. farmers) (CHE 2014). Thus, the decision to exhaust the storage capacity of reservoirs within a catchment is a robust (low risk) decision with respect to water availability. In this context floods do constitute greater risk since they don't allow exhausting the total storage capacity due to dam safety reasons (CHE 2014).

Usability of S2D climate forecast information: decision-making of water managers refers to the fill-level of the reservoir which is aimed to be exhausted at the end of the rainfall season but requires considerations of in-seasonal release rates due to flood-protection, ecological system maintenance and other reasons. Thus, decision-makers are interested in total water available at the end of the rainy season. Discharge rates during the season and thus the timing of high- and low-flow events are of minor importance with respect to this goal. This interest is systemically and technically supported by the buffer effect of the catchment and dam reservoirs. Consequently, information on mean temperature and effective rainfall over a certain period is general desired and usable due to the systemic buffering of rainfall and evapotranspiration rates by the catchment and reservoir system. Furthermore, since temporal scales of the critical climate conditions is much longer than the temporal scale of decision-making seasonal climate forecasts doesn't need to cover the entire time-scale. At the time of decision-making a great deal can be covered by using climatology.

The matter of timing is however an issue for the coping of flood events. Especially when approaching the end of the rainy season and the reservoir is rather full and the timing of high-magnitude flood events is critical information. Thus, climate information with higher temporal resolution would be desired to reduce uncertainty of such events. This information would be particularly useful for improving the decision taking in the Reservoir Releases Commission in October (e.g. maximum and minimum release during winter, maximum reservoir filing to buffer potential flood) and March (e.g. minimum reserve in dams at the end

of the irrigation period, end of irrigation period). Compared to problems of other sectors the need for high ***spatial resolution*** is limited (e.g. most of the dams have upstream basins of more than 500km^2) and thus the tolerance to lower spatial resolution is expected to be higher. Furthermore, since water resource operation management and planning are generally based on historical climate (discharge) data, worst-case scenarios are commonly used in planning (e.g. drought management plan, dam capacity) and recent records used in operation (e.g. average of last 10 years inflow records used in the user´s assemblies). The use of climate forecast could be easier for the stakeholders if some references are made with recent historical events (e.g. prediction of more or less rainfall than the last 10 years).