**"Droughts do not always occur under the same conditions, neither socio-economic nor hydrologic."**

# Introduction

The Júcar River Basin District (JRBD), in South Eastern Spain, has an irregular hydrology, which is very characteristic of Mediterranean basins. The JRBD is one of the most vulnerable areas to drought in the Western Mediterranean region due to semi-aridity, high water consumption, hydrological variability, and environmental and water quality problems when droughts appear.

Recent major drought events occurred in 1983-1986, 1992-1995, 1998-2000, and 2005-2008. The most severe impacts concentrated on the agriculture and hydropower sectors: in case of a drought, these two sectors have lower priority for water supply, compared to urban water supply and supply to environmentally sensitive areas. The reoccurrence of drought episodes has triggered an increased use of non-conventional resources, such as reuse of wastewater or desalination of seawater, conjunctive use of surface-ground waters, purchase of water rights, and the improvement of purification treatments to deal with higher pollutants concentrations.

It is likely that the succession and impacts of dry-humid periods will increase in the future, due to increasing human pressures and climate change. Moreover, the Water Framework Directive (WFD) (EC, 2000) requirements imply that more water will be assigned to environmentally vulnerable areas.

Based on this context, the main goal of the ENHANCE project was **to develop strategies to minimise the risk of drought episodes in the JRBD, and to improve resilience**. This is done by enhancing existing Multi-Sectorial Partnerships (MSPs), and by assessing current and new disaster risk reduction (DRR) measures and whether they can be adopted by the MSPs.

Photo by Aleksandr Petrunovskyi/Shutterstock.

Júcar-Turia Canal at Alzira. Photo by Jaime Gaona.

Tous reservoir in the middle course of Júcar River.
Photo by Jaime Gaona.

# The JRBD partnership (CHJ)

Stakeholder participation and development of partnerships have been of great importance for the management of droughts within the JRBD. Historically, drought management has been mainly carried through infrastructure development, and existing MSPs have been developed around water supply measures. Initially, single-sectorial partnerships were predominant, but in 1936 the **JRBD Partnership (CHJ)** was created, which included all major sectors of water users, as well as national, regional and local governments' representatives. The role of this MSP has evolved over time, and nowadays the CHJ is in charge of the different aspects of water planning and management including infrastructure development, floods and droughts mitigation, protection of public water domain, and environmental objectives.

Strategies and measures for planning horizons are defined in River Basin Management Plans (RBMPs) as required by the WFD. However, the diversification of interests within the CHJ revealed the need for the division of the decision-making process into several internal bodies, which still include most stakeholders. Therefore, a cluster of satellite MSPs has been created along the years to deal with the different problems existing within the Júcar RBD. This is the case of the **Permanent Drought Commission (CPS)**, which is activated by means of a Royal Decree when an emergency drought stage is declared, until recovery of normality. The CPS is in charge of applying the DRR measures against drought defined in the Drought Special Plan (DSP), and defining additional measures if necessary. With the support of the Drought Technical Office, the CPS assesses risks and discusses and sets the necessary measures to increase resilience and to mitigate the effects that drought might have on the water supply system. All the stakeholders within the CPS act under an equality basis, and decisions are usually made by consensus. All the participants have access to all the existing data and analysis regarding the risk and the effects of the different measures studied.

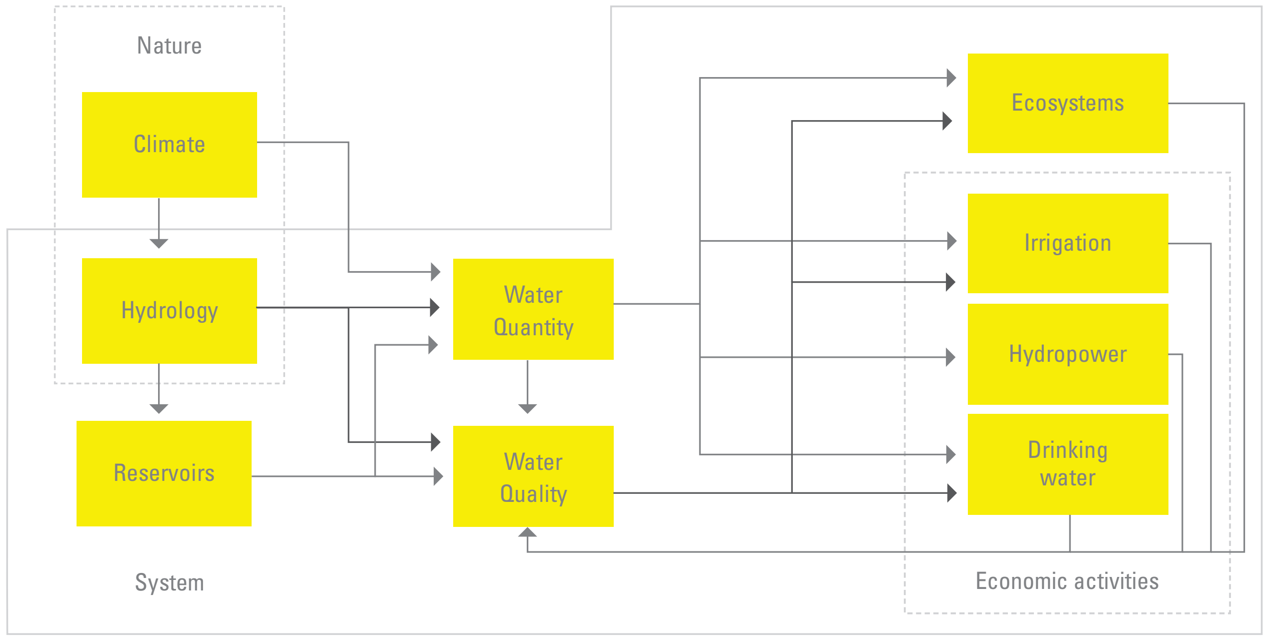
**Photo by orxy/Shutterstock.**

# Risk assessment

### *Tools and results*

Different risk assessment tools[24] are available for the JRBD Partnership, and some of these are used for participative decision-making, and to analyse the efficiency of the possible measures against drought. This involves the implementation of a series of models and methodologies to assess current and future risk, and are schematically displayed in Figure 15.1.

**Figure 15.1.**
Elements considered in the risk analysis.



For the planning horizon, the deterministic water allocation model SIMGES was run using the river discharges resulting from the hydrological model EVALHID, assuming different scenarios. Table 15.1 shows the volumetric reliability (average annual supply/annual demand) for the demands in the Júcar River Basin for 6 scenarios. The scenarios are:

- Baseline scenario 0: Historical streamflow time series from 1940 to 2008-09, current water demands and infrastructures.
- Scenario 1: Near-future situation: streamflow series from 1980-81 to 2008-09.
- Scenario 2: Medium-long future situation: streamflow and renewable groundwater reduction from CEDEX-DGA (2011).
- Scenario 3: Long future situation (2040-2070): streamflow series from HadCM2 model.
- Scenario 4: Very long future situation (2070-2100): using the same model as scenario 3.
- Scenario 5: Very long future situation (2070-2100): streamflow series from the regional model PROMES (Gallardo et al., 2001) nested in the HadCM3 model (Pope et al., 2000) in the emissions scenario SRES-B2.
- Scenario 6: Like scenario 5 but changing the emissions scenario to SRES-A2.

Results indicate that for the short- and mid-term, the supply to all demands would remain high, but on the long-term, all demands would suffer water scarcity. Especially agricultural demands and the urban demand of Albacete face water scarcity.

The main conclusion based on the results is that drought impacts are very likely to increase in the future and, thus, **it will be necessary to pay special attention to system management and optimisation**. The improvement of indicators systems and the need of advanced prevention and mitigation measures should become a priority. In the same way, it will be necessary to define new adaptation and/or DRR strategies to cope with negative effects.

[24]Available models comprise hydrological- deterministic approaches: hydrological model EVALHID (Pedro-Monzonís et al., 2013), stochastic models: ARMA model MASHWIN (Sánchez-Quispe, 1999) –, water allocation simulation: SIMGES (Andreu et al. 1996), and probabilistic models: SIMRISK (Andreu and Solera, 2006); water allocation optimisation models: OPTIGES (Haro, 2014); probabilistic models: OPTIRISK (Haro 2014; Haro et al., 2014) –, water quality analysis – at river basin scale: GESCAL (Paredes et al., 2010), and at drinking water treatment plant (DWTP) scale: Microbiological Risk Assessment Tool (Macián-Cervera, 2015) –, hydro-economic analysis – SIMGAMS (with simulation of water management based on priorities and economic post-processor) and OPTIGAMS (with optimization of water management based on maximization of economic efficiency) respectively (Lopez-Nicolas, 2014).

**Table 15.1.**

Vulnerability results for the Júcar River Basin demands under 6 different scenarios.

| | Scenario 0 | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| Urban Demand | 100.00% | 100.00% | 99.80% | 91.41% | 86.97% | 82.95% | 75.91% |
| Albacete | 100.00% | 100.00% | 100.00% | 51.94% | 43.53% | 43.51% | 40.34% |
| Valencia | 100.00% | 100.00% | 99.75% | 98.76% | 94.94% | 90.08% | 82.06% |
| Sagunto | 100.00% | 100.00% | 99.75% | 99.19% | 96.75% | 93.01% | 87.92% |
| Irrigation Demand | 99.56% | 98.42% | 95.79% | 86.60% | 79.51% | 63.39% | 54.56% |
| Mancha Oriental | 99.70% | 98.94% | 97.20% | 95.18% | 92.45% | 88.40% | 86.81% |
| Júcar-Turia Canal | 99.67% | 98.50% | 95.46% | 89.50% | 82.54% | 54.76% | 44.50% |
| Ribera Alta | 99.66% | 97.87% | 94.09% | 74.95% | 60.94% | 35.48% | 20.85% |
| Ribera Baja | 99.75% | 98.58% | 95.49% | 85.00% | 76.53% | 59.13% | 47.91% |

In real time management and early warning, it is necessary to monitor the evolution of drought in order to decide when to activate each DRR measure. In the case of the Júcar and Turia River Basins, the 'state drought indicator' (Haro et al. 2014) as defined in the DSP (Drought Special Plan) shows the state of drought in the Júcar basin. However, this indicator can be improved if it is combined with the results provided by the OPTIRISK model used as an early warning system. It requires stochastic flow series from MASHWIN, which are based on historical streamflow patterns. The evolution of the index as calculated with OPTIRISK shows a similar behaviour with regard to the drought events occurred in the Júcar River Basin, but it is a little more alarming (Figure15.2).

When the officially measured drought indicator enters for two consecutive months in the 'emergency state' (Figure 15.2), the DSP (Drought Special Plan) is set into action, and is being coordinated by the Drought Technical Office. If the drought indicator remains for two consecutive months in the emergency state, a drought episode is officially declared. Then, the CPS is in charge of assessing and implementing the measures envisaged in the DSP. For this particular drought stage, results of SIMGES and SIMRISK models are combined to show the effects of the situation with- and without measures (Figure 15.3).

**Figure 15.2.**

Evolution of the 'state drought index' in the Turia River system calculated from the SIMGES results (blue), from OPTIRISK results (dashed black), and official CHJ values (black), compared to the drought scenario thresholds.

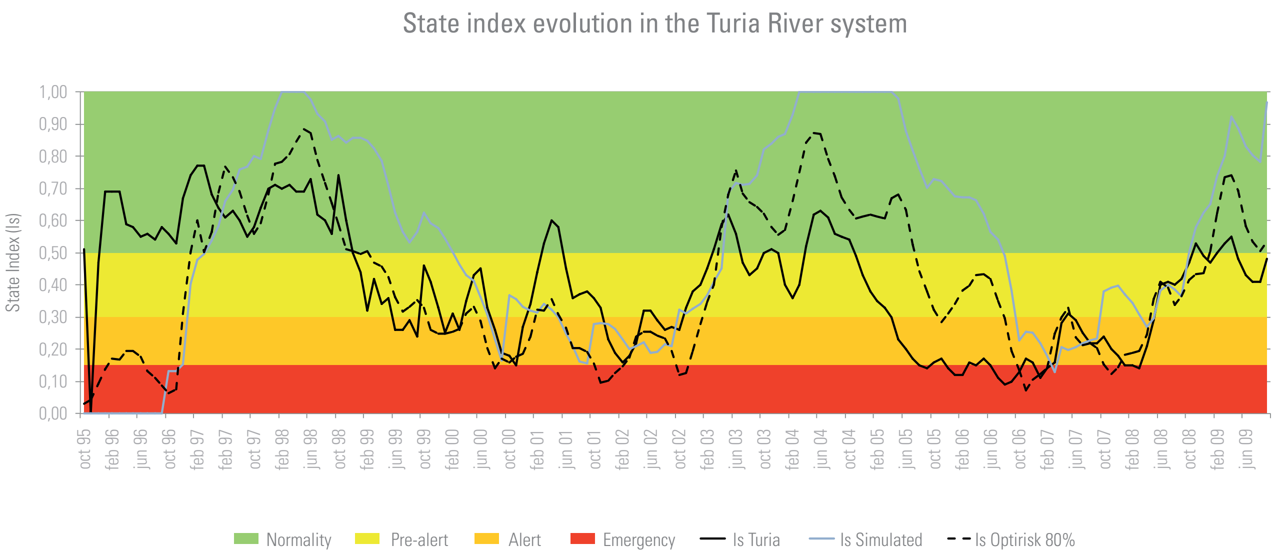
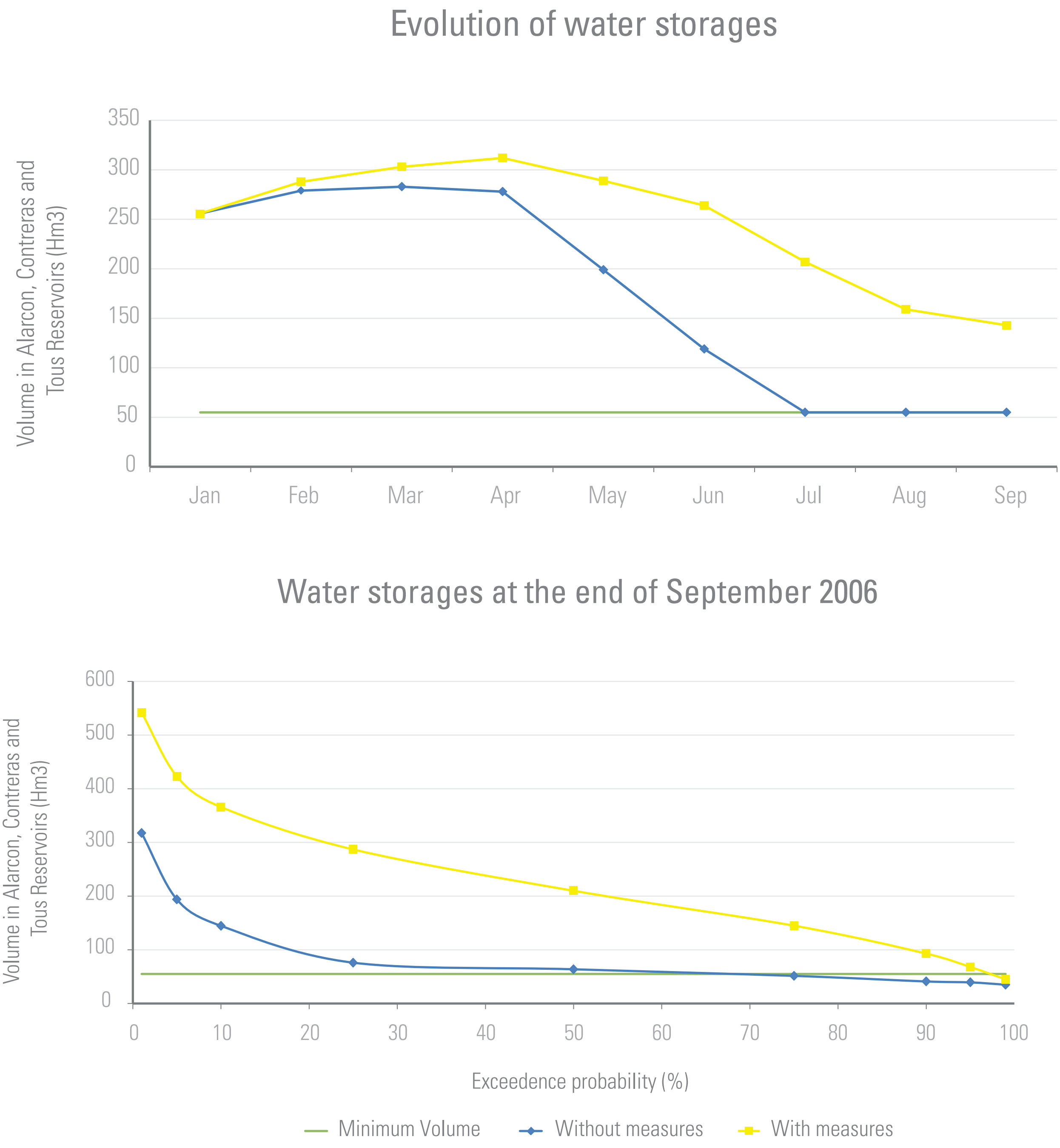


**Figure 15.3.**

Effects of an emergency drought with (yellow) and without (blue) drought reduction measures using two models: Deterministic (left) and probabilistic (right) forecasts for the Júcar reservoirs storage evolution in 2006 campaign.



***Water pricing and risk***

The potential of economic instruments to manage drought risk has been analysed through *hydro-economic models*, (HEMs) (Pulido-Velazquez et al., 2008). The use of HEMs allows calculating *water scarcity costs* as the economic losses due to water deliveries below the target demands, which can be used as a vulnerability descriptor of drought risk (Lopez-Nicolas et al., 2015).

Figure 15.4 shows the scarcity-based water pricing policy of the Alarcón reservoir, the main surface reservoir of the Júcar system with a capacity of 1112 Mm3. It was obtained with the SIMGAMS model, based on the marginal resource opportunity cost at a specific location and time, which can be defined as the system-wide benefit of having available one additional unit of resource at that location and time (Pulido-Velazquez et al., 2013). This step water pricing policy allows sending a signal to the MSPs, since the price is higher when the storage is lower (ranging from 0.31 €/m$^3$ to 0 €/m$^3$).

Figure 15.5 shows that the total water scarcity cost (foregone benefits during droughts) would be lower in the Júcar River Basin when water pricing policies are applied, as compared to the business as usual scenario. The consequence of pricing policies would be the reduction of total economic losses during drought periods, with more water available for high-value crops at the expense of low-value crops. Furthermore, simulations to optimise water allocation show that water markets would significantly reduce the total water scarcity cost, with voluntary water transfers from low-value crops to higher value crops during drought periods.

***Water quality***

Regarding water quality, the World Health Organisation (WMO) identified *cryptosporidium* as the most dangerous emergent pathogen for urban water supply. We analysed the health risk caused by this microbe for the supply to the city of Valencia during low flow conditions at two different scales. On the one hand, water quality model GESCAL was used to determine the effect of drought on cryptosporidium concentrations at a river basin scale (Figure 15.6). Since the number of pathogens in water is very difficult to measure directly, we used the total and fecal coliforms as indicators (Carmena et al., 2007).

On the other hand, we applied a methodology to quantify risk of cryptosporidium presence in the most known, classical and extended drinking water treatment, the conventional treatment. The risk model is based on facilites' simple on-line operational parameters and the results are the health risk estimation for the served population. We used the relationship between risk and microbiological concentration (Macián-Cervera, 2015).

**Figure 15.4.**
Scarcity-based water pricing policy for Alarcón reservoir.

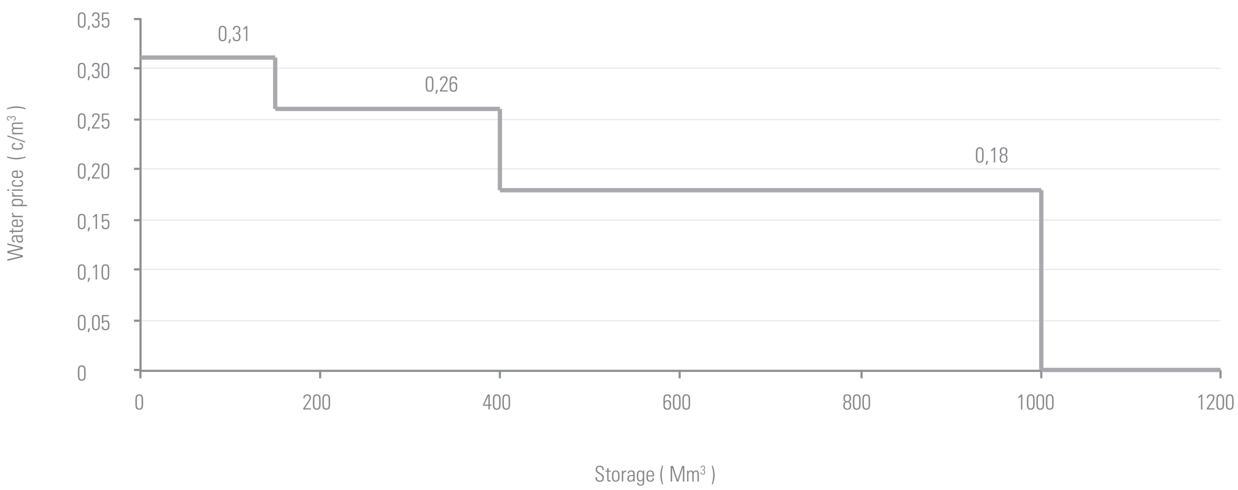


**Figure 15.5.**
Water scarcity cost comparison between business-as-usual scenario and the water pricing policies scenario.

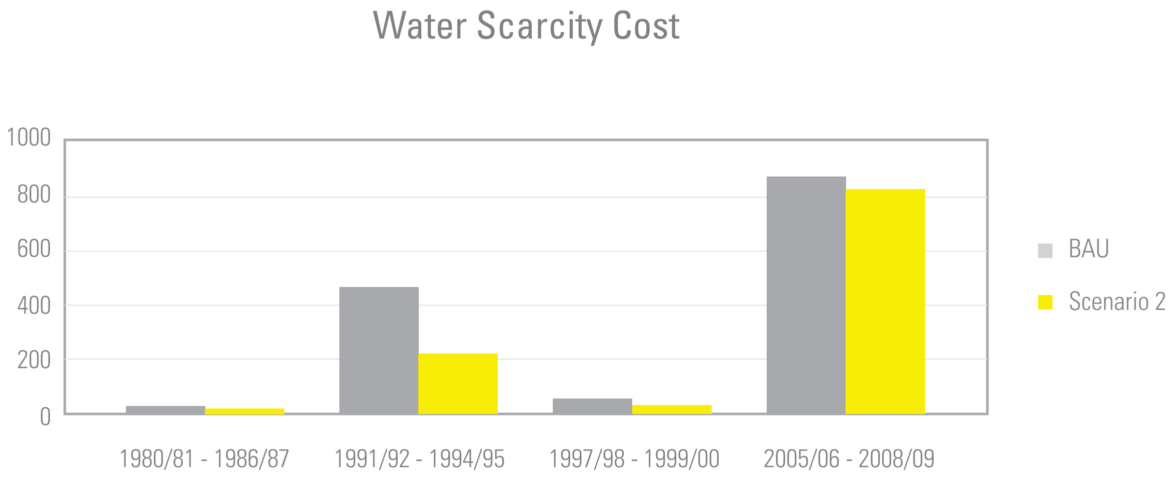



**Figure 15.6.**
Comparison between average concentrations of fecal coliforms simulated in calibration scenario, scenario 1 (reduction of 15% of streamflows) and scenario 2 (reduction of 30% of streamflows).