Water supply systems planning under uncertainty: defining a procedure for the evaluation of investment and management alternatives

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Uncertainty and robustness in water supply systems

Concept

The idea of 'robustness' has received increasing international attention in recent years in the development of methodologies for the analysis and planning of water systems, dealing with the uncertainty given by the effects of climate change, trends of water usage and other socio-economic aspects. The concept of robustness differs from the classic concept of optimality in that, while the latter pursues pure performance in average terms, robustness leads to a solution that performs well under various possible future conditions, safeguarding the water system from the most unfavourable future scenarios in terms of the balance between supply and demand for water resources.

The aim of the research project is to analyse and define all aspects that come into play and define a comprehensive procedure for the selection of investments that is adaptable to different water systems and types of alternatives.

Scientific approach

An important step is the generation of hydrological scenarios accounting for climate change. There are basically two different approaches to do this, and both will be tested and compared. On the one hand, forecasts of the Euro-Mediterranean Centre on Climate Change (CMCC) will be used to obtain time-series of plausible future inflows; on the other hand, hydrological forecasts will be obtained with techniques based on historical data, and the resulting time series will be perturbed to take into account the effects of climate change, according to the recent literature.

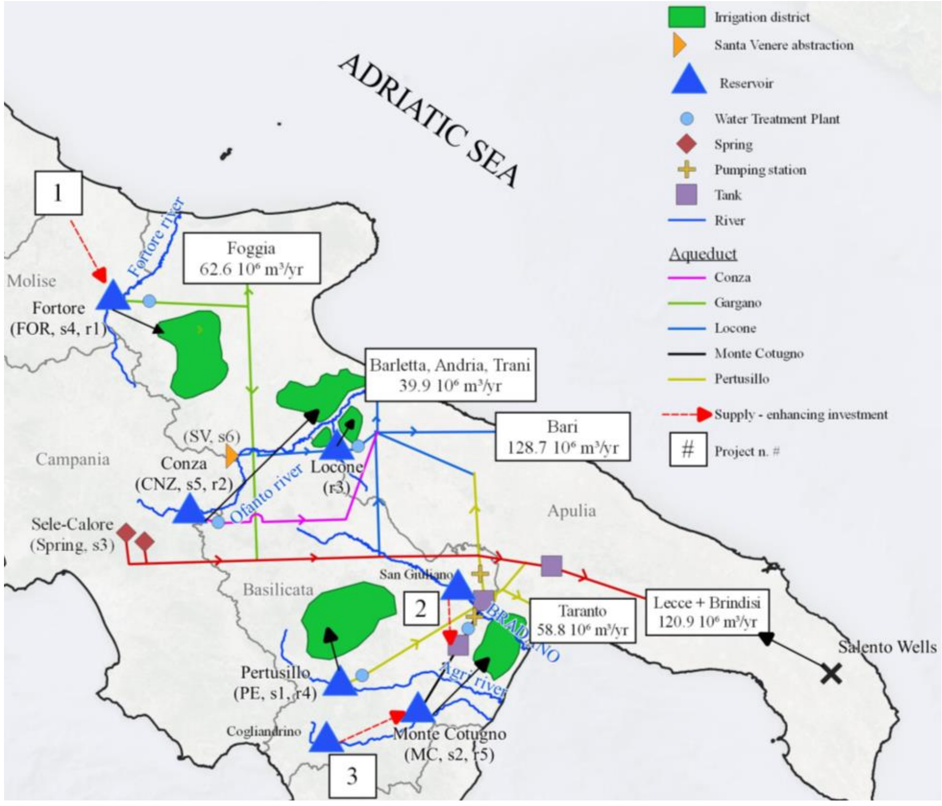
Demand scenarios will also be generated based on different socioeconomic aspects.

The different elements of uncertainty will be examined analytically and separately and will eventually enter the process of evaluating water infrastructure projects and policies. Robustness metrics will be selected, and an algorithm based on these metrics will be defined to support decision making.

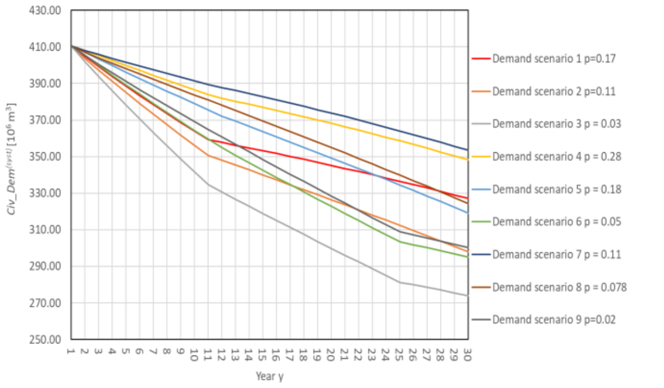
Research objectives

- Investigation on the technique for the generation of hydrological forecasts, accounting for climate change
- Investigation on future changes in civil, irrigation and industrial water demand
- Investigation on the different robustness metrics
- Definition of a comprehensive, practical procedure to support decision making among a set of candidate investment or policy alternatives for water supply systems

Water supply system and candidate alternatives



Demand and hydrological scenarios



Robustness metrics

Metric	Formula
Expected NPV	$\max\left(\sum_{i=1}^{Nsc} p_i X_i, \sum_{i=1}^{Nsc} p_i Y_i, \sum_{i=1}^{Nsc} p_i Z_i\right)$
Laplace principle of insufficient reason	$\max\left(\frac{1}{Nsc} * \sum_{i=1}^{Nsc} X_i, \frac{1}{Nsc} * \sum_{i=1}^{Nsc} Y_i, \frac{1}{Nsc} * \sum_{i=1}^{Nsc} Z_i\right)$
Maximin	$\max(X_{i^{*1}} = \min_{i=1}^{Nsc} X_i, Y_{i^{*2}} = \min_{i=1}^{Nsc} Y_i, Z_{i^{*3}} = \min_{i=1}^{Nsc} Z_i)$
Maximax	$\max(X_{i^{**1}} = \max_{i=1}^{Nsc} X_i, Y_{i^{**2}} = \max_{i=1}^{Nsc} Y_i, Z_{i^{**3}} = \max_{i=1}^{Nsc} Z_i)$
Hurcwiz optimism-pessimism rule	$\max\left(\frac{(p_{i^{*1}} X_{i^{*1}} + p_{i^{**1}} X_{i^{**1}})}{(p_{i^{*1}} + p_{i^{**1}})}, \frac{(p_{i^{*2}} Y_{i^{*2}} + p_{i^{**2}} Y_{i^{**2}})}{(p_{i^{*2}} + p_{i^{**2}})}, \frac{(p_{i^{*3}} Z_{i^{*3}} + p_{i^{**3}} Z_{i^{**3}})}{(p_{i^{*3}} + p_{i^{**3}})}\right)$
Minimax regret	$\min\{\max_{i=1}^{Nsc}[\max(X_i, Y_i, Z_i) - X_i], \max_{i=1}^{Nsc}[\max(X_i, Y_i, Z_i) - Y_i], \max_{i=1}^{Nsc}[\max(X_i, Y_i, Z_i) - Z_i]\}$
90th percentile minimax regret	$\min\left(P_{90}(\{\max(X_i, Y_i, Z_i) - X_i\}_{i=1}^{Nsc}), P_{90}(\{\max(X_i, Y_i, Z_i) - Y_i\}_{i=1}^{Nsc}), P_{90}(\{\max(X_i, Y_i, Z_i) - Z_i\}_{i=1}^{Nsc})\right)$
Undesirable deviations	$\min\left(\sum_{j=1}^{Nsc/2} \bar{X}_j, \sum_{j=1}^{Nsc/2} \bar{Y}_j, \sum_{j=1}^{Nsc/2} \bar{Z}_j\right)$ with $\bar{X}_j$ the worst − half samples (higher values) of $\bar{X}_i = \max[0, \mathrm{median}(X_i, Y_i, Z_i) - X_i]$, the regret from median value. Similarly, for Y and Z.
Starr's domain criterion	$\max\left(\sum_{i=1}^{Nsc} I(X_i > 0), \sum_{i=1}^{Nsc} I(Y_i > 0), \sum_{i=1}^{Nsc} I(Z_i > 0)\right)$ $I(\cdot) = 1$ if $(\cdot) = true$, $I(\cdot) = 0$ otherwise

		Demand scenarios								
		1	2	3	4	5	6	7	8	9
Supply scenarios	1	3	3	3	2	3	3	2	3	3
	2	3	3	3	3	3	3	3	3	3
	3	3	3	3	3	3	3	3	3	3
	4	2	3	3	2	3	3	2	3	3
	5	3	3	3	3	3	3	3	3	3
	6	3	3	3	3	3	3	3	3	3
	7	2	3	3	2	2	3	2	2	3
	8	3	3	3	3	3	3	3	3	3
	9	3	3	3	3	3	3	3	3	3

Results of metrics -> choice of investment

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