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HS3.1 – Hydroinformatics: computational intelligence, systems analysis, optimisation, data science



Hydronomeas 2020: Open-source decision support system for water resources management

George Karavokiros, Dionysios Nikolopoulos, Stavroula Manouri, Andreas Efstratiadis, Christos Makropoulos, Nikos Mamassis, and Demetris Koutsoyiannis

Department of Water Resources & Environmental Engineering
National Technical University of Athens, Greece


Presentation available online: www.itia.ntua.gr/2020/



From retro HydroInformatics applications...

Υδρομετεωρολογικός Χάρτης

Πλαίσιο Ομάδα Σταθμοί Κριτήρια Επιλογές Οδηγίες

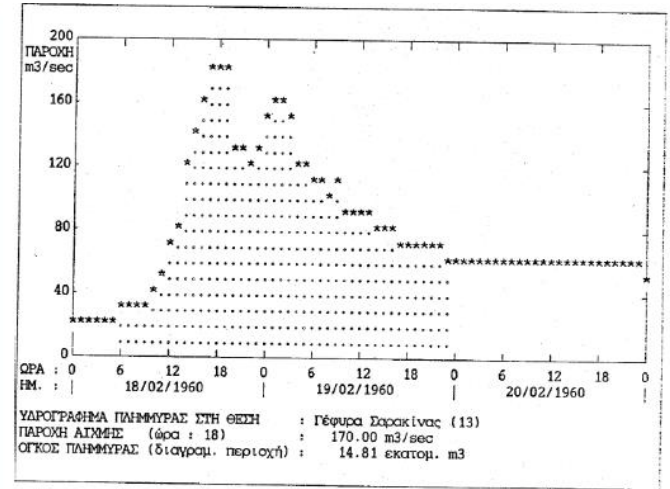


**Γραφικό περιβάλλον
Unix/X-Windows
Χάρτες
Μητρώο μετρητικών σταθμών**

Μητρώο σταθμών

Πλαίσιο Ομάδα Κριτήρια Λειτουργίες Επιλογές Οδηγίες

Όνομα	Κωδός	Υψηροσία	φ	λ
ΑΓΙΟΣ ΑΝΝΗΤΡΙΣ	ΑΙΤΣΑΚΑΡ	ΔΕΗ	37.40.00	21.50.00
ΑΓΡΑΦΙΩΤΗΣ	ΕΥΡΥΤΑΝ	ΔΕΗ	39.01.00	21.36.00
ΑΧΕΛΩΙΣ ΑΥΛΑΚΙ	ΚΑΡΑΙΤΣΑ	ΔΕΗ	39.10.00	21.17.00
			21.44.00	
			21.41.00	
			21.41.00	

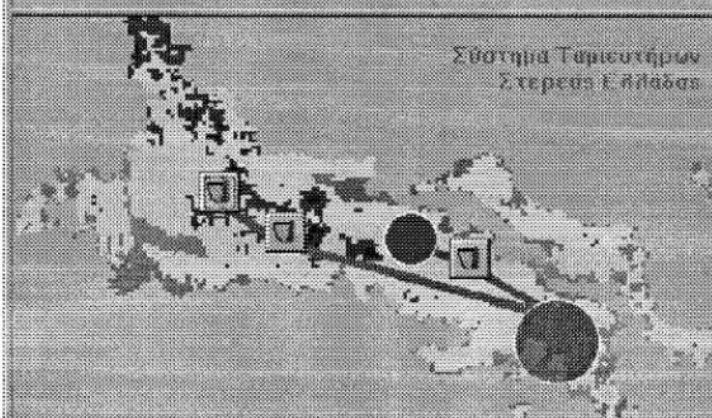


Γενετική προσομοίωση D:\SIMULATE\5000.GSM

Αρχείο Επιχειρησικά Λειτουργίες Οδηγίες

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Συστήρια Τελεωτήριων
Στερεας Ε. Ελλάδας



Υδατικό ισοζύγιο Διαγράμματα Υδατικό σύστημα Αρχείο

Γενετική προσομοίωση D:\SIMULATE\5000.GSM

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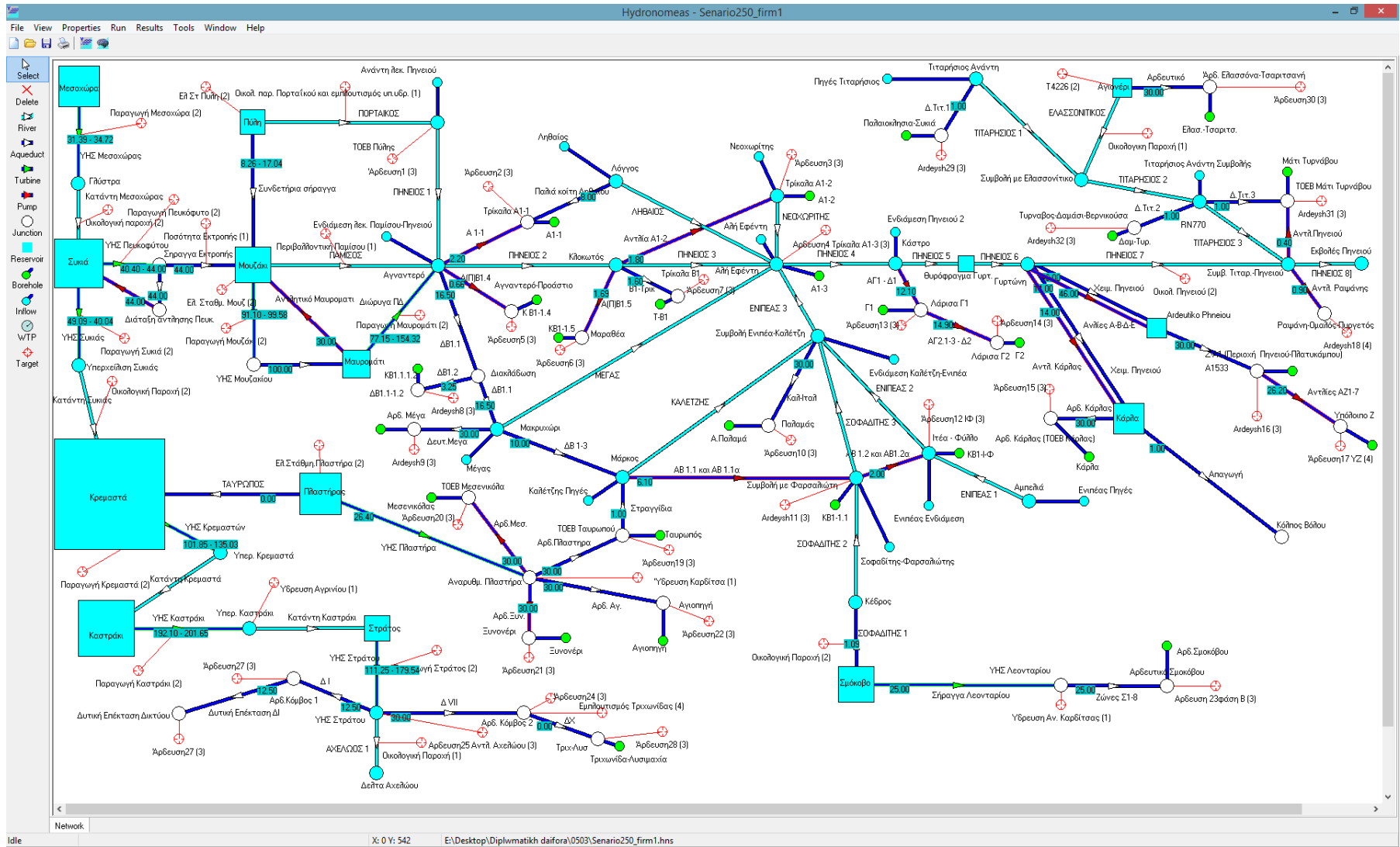
Πιθανότητα αστοχίας 0.01000

	Εόηθος	Μήνιος	Υλική	Σύνολο
Απορροή	321.143	311.041	353.246	985.430
Βροχή	3.945	27.040	7.941	38.926
Εξάτμιση	3.807	24.511	24.649	52.967
Διαρροή	0.000	12.678	96.162	108.840
Υπερχειλίση	74.778	31.170	4.279	110.227
Υδρευση	0.000	516.216	187.357	703.573
Χρδευση	0.000	0.000	48.905	48.905
Ανταλλαγή	-246.491	246.491	0.000	0.000

Υδατικό ισοζύγιο (hm³)

Υδατικό ισοζύγιο Διαγράμματα Υδατικό σύστημα Αρχείο

... to a modern DSS...



Source: Koukouvinos et al., 2015

... to a new open source python package (soon)!

The image shows the Spyder Python IDE interface. The main window displays a Python script named `test_oper_rule.py` with the following content:

```
1 #-*- coding: utf-8 -*-
2 """
3 Created on Fri Sep 13 11:43:31 2019
4
5 @author: dionisis
6 """
7 import numpy as np
8 import networkx as nx
9 import hydroElements as he
10 import realNetworkGraph as rNG
11 import mathModel as mM
12 import simpleSimulation as sim
13 import hyplot
14 import inputOutputModule as io
15
16 import matplotlib.pyplot as plt
17 import time
18
19 import simResultParser
20 import os
21 import operational_rule
22
23 currentDirectory = os.getcwd()
24
25 ## Load Objects and Timeseries
26 LS1=io.readLevelSurfaceCurveFromExcel(currentDirectory+"\testData\MornosLSV.xlsx")
27 LV1=io.readLevelVolumeCurveFromExcel(currentDirectory+"\testData\MornosLSV.xlsx")
28
29 LS2=io.readLevelSurfaceCurveFromExcel(currentDirectory+"\testData\YlikLSV.xlsx")
30 LV2=io.readLevelVolumeCurveFromExcel(currentDirectory+"\testData\YlikLSV.xlsx")
31
32 RRE1=io.read_RRE_TS_from_Excel(currentDirectory+"\testData\Mornos_Timeseries_2.xlsx")
33 RRE2=io.read_RRE_TS_from_Excel(currentDirectory+"\testData\Ylik_Timeseries_2.xlsx")
34
35 leakageMatrix1=io.read_leakage_matrix_from_excel(currentDirectory+"\testData\Mornos_leakage.xlsx")
36 leakageMatrix2=io.read_leakage_matrix_from_excel(currentDirectory+"\testData\Ylik_leakage.xlsx")
37
38 resA=he.Reservoir('Mornos', (22.19, 38.49), LV1, LS1, 586, 384, 435, 411, RRE1[0], RRE1[1], RRE1[2], leakageMatrix=leakageMatrix1) #411.33 le
39 resB=he.Reservoir('Ylik', (20.19, 40.49), LV2, LS2, 2354, 43.5, 79.8, 62.54, RRE2[0], RRE2[1], RRE2[2], leakageMatrix=leakageMatrix2)#leakag
40 boreholeGroup=he.Borehole('BG', (22, 39), abstractionLimit=np.array([2]), cost=np.array([1.1]))
41
42
43
44 A=he.Junction('Athens', (23.73, 37.97), Z=0)
45 J1=he.Junction('J1', (24.73, 37.97), Z=0)
46 J2=he.Junction('J2', (22.73, 37.97), Z=0)
47
48 aque1=he.Channel('Y-J1', 'Ylik', 'J1', np.array([50]), leakage=np.array([np.float64(0)]))
49 aque2=he.Channel('J1-A', 'J1', 'Athens', np.array([50]), leakage=np.array([np.float64(0)]))
50 aque3=he.Channel('M-J2', 'Mornos', 'J2', np.array([50]), leakage=np.array([np.float64(0)]))
51 aque4=he.Channel('J2-A', 'J2', 'Athens', np.array([50]), leakage=np.array([np.float64(0)]))
52
53 targetval=io.read_target_from_excel(currentDirectory+"\testData\Node_Demand.xlsx")
54 ADemand=he.Target('AthensMonthly', 'water_supply', targetval, priority=1)
55
56 targetval=io.read_target_from_excel(currentDirectory+"\testData\Ylik_demands.xlsx")
57 YDemand=he.Target('YlikMonthly', 'water_supply', targetval, priority=2)
58
59 targetval=io.read_target_from_excel(currentDirectory+"\testData\mornos_demands.xlsx")
60 MDemand=he.Target('YlikMonthly', 'water_supply', targetval, priority=2)
61
62 ## Create Network
63 G=rNG.networkGraph()
64 G.addReservoir(resA)
65 G.addBorehole(resB)
```

The console window shows the following output:

```
...: # G.addBorehole(boreholeGroup, 'J1')
...: G.addJunction(A)
...: G.addJunction(J1)
...: G.addJunction(J2)
...: G.addChannel(aque1)
...: G.addChannel(aque2)
...: G.addChannel(aque3)
...: G.addChannel(aque4)
...: G.addTarget(ADemand, 'Athens')
...: G.addTarget(YDemand, 'J1')
...: G.addTarget(MDemand, 'J2')

In [2]: s=sim.SimulationScenario(G, 23988)
Using license file C:\Users\dionisis\gurobi.lic
Academic license - for non-commercial use only

In [3]: t = time.process_time()
...: z.run_sim()
...: elapsed_time = time.process_time() - t
...: print("Execution Time", elapsed_time)
Execution Time 18.53125

In [4]:
...: res=simResultParser.simResults(z)
...: res.createTargetPandasTable()
...: res.TargetMetricDF

Out[4]:
           Reliability  Failed Steps  Mean step deficit  Max Deficit
AthensMonthly      0.930632         1664      1.428595      36.342932
YlikMonthly         0.079498         22081      0.537357      14.611000
YlikMonthly         0.079498         22081      0.537357      14.611000

In [5]:
```



Project description

□ Objective

- Provide a full featured DSS python module (Hydroneas 2020) for water systems, providing all the original functionality of Hydroneas v.4.9 plus many more enhancements. Initially script-based, with a new GUI on its way!

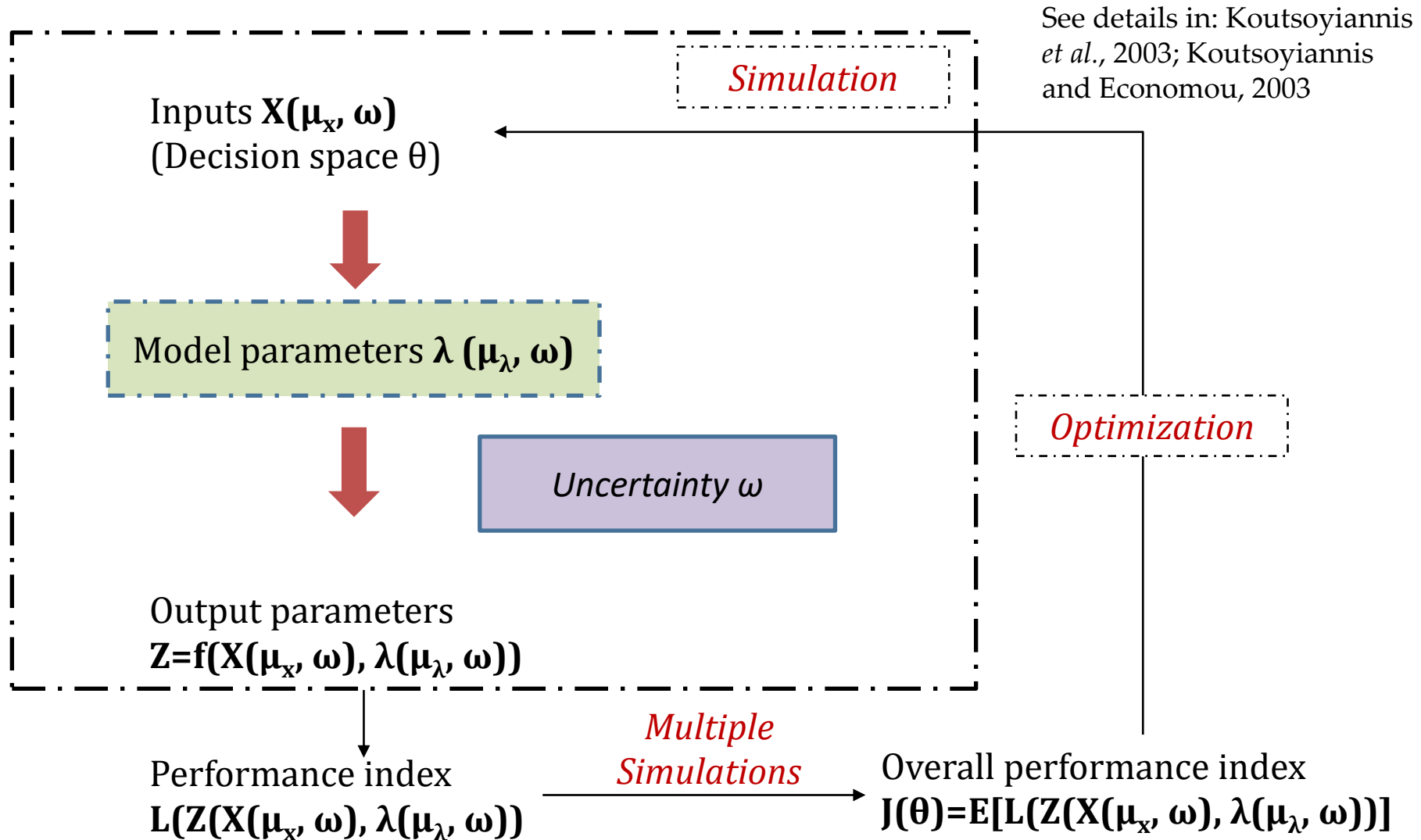
□ Key enhancements

- Terminating and end-state water system simulations under uncertainty, operationalization of the water system's resilience (Makropoulos et al., 2018; Nikolopoulos et al., 2019);
- Arbitrary simulation time scale (e.g. monthly, daily or higher temporal resolution, depending on available input data);
- Dynamic component attributes through simulation (e.g. can simulate the aging of an aqueduct through time and its replacement) and incorporation of stochastic demand timeseries;
- New reservoir operational rules with simpler parameters and ability to distribute water deficits across a larger time horizon;
- Global energy production optimization in systems with complex topology;
- Two options for solving the water allocation problem in each step of the simulation: i) the very fast commercial solver Gurobi, provided that the user acquires a license and ii) the open source scipy linprog solver, provided with the Anaconda Python distribution;
- Easy problem formulation and connection to virtually all optimization algorithms available for Python;
- Dependencies: the user needs only the Anaconda distribution to run the basic program.

Links with Python scientific packages

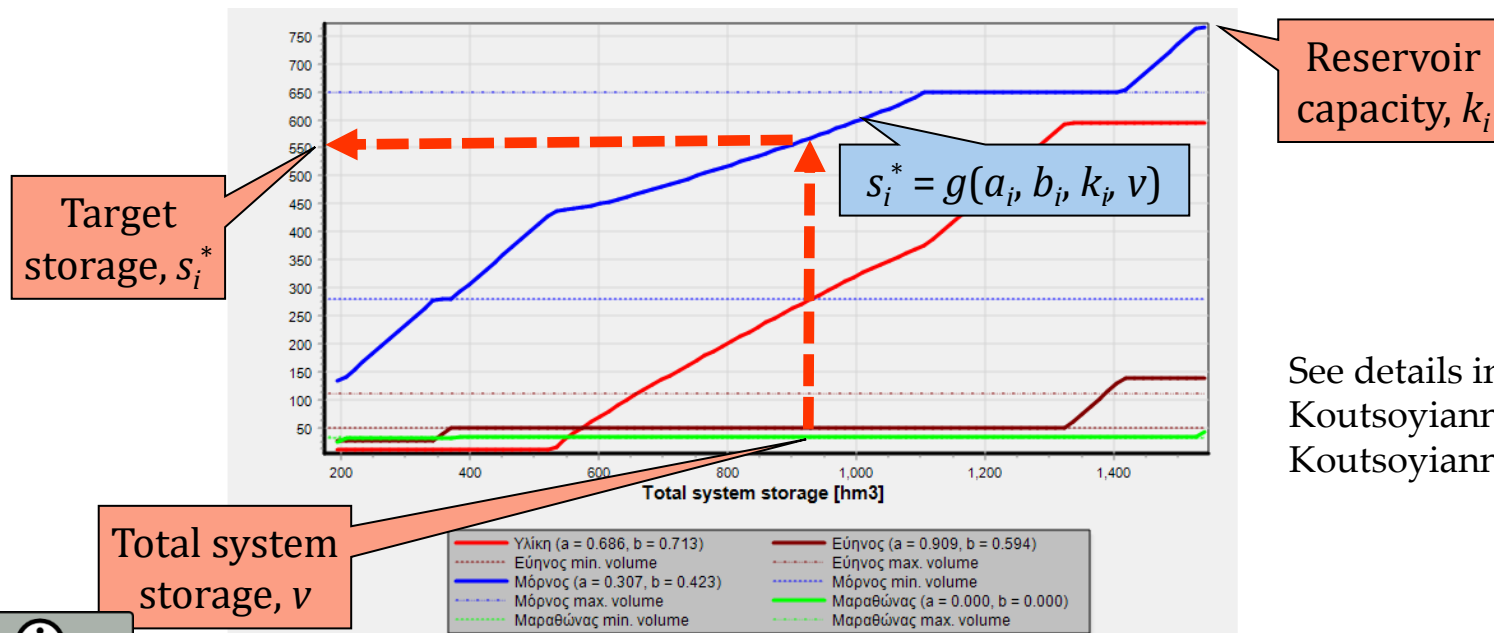
- **Modularity** and **easy extensibility** is ensured as Hydronomeas 2020 is purely Python based and object-oriented. All of the modules and classes are implemented using as dependencies well known Python scientific packages, namely:
 - *NetworkX*, for the representation of the real water system topology and the mathematical digraph of the system
 - *Numpy*, for all algebraic operations with vectors, matrices and scalars in the mathematical formulation of the water system
 - *Scipy*, for the linear programming solvers for water allocation in the iterations for sparse matrices and the global optimization routines
 - *Matplotlib*, for visualization purposes (results, topology graphs etc.)
 - *Pandas*, for handling input and output data (timeseries, tables, curves, etc.)
- Hydronomeas 2020 currently consists of 4 primary modules:
 - *hydroelements*: classes of the real water system objects implementing their behaviour (reservoirs, pumps, turbines, targets, rivers, boreholes, etc.)
 - *realNetworkGraph*: allows the representation of a system as a network graph of *hydroelements* instances
 - *mathModel*: allows the representation of a system's network graph as a mathematical model of linear programming in each iteration
 - *simulationScenario*: defines and runs a simulation scenario for the water system
 - plus, many other helper modules e.g. for data input, result export, connection to global optimization procedures, visualization etc.

Methodological backbone: Parameterization - stochastic simulation-optimization framework



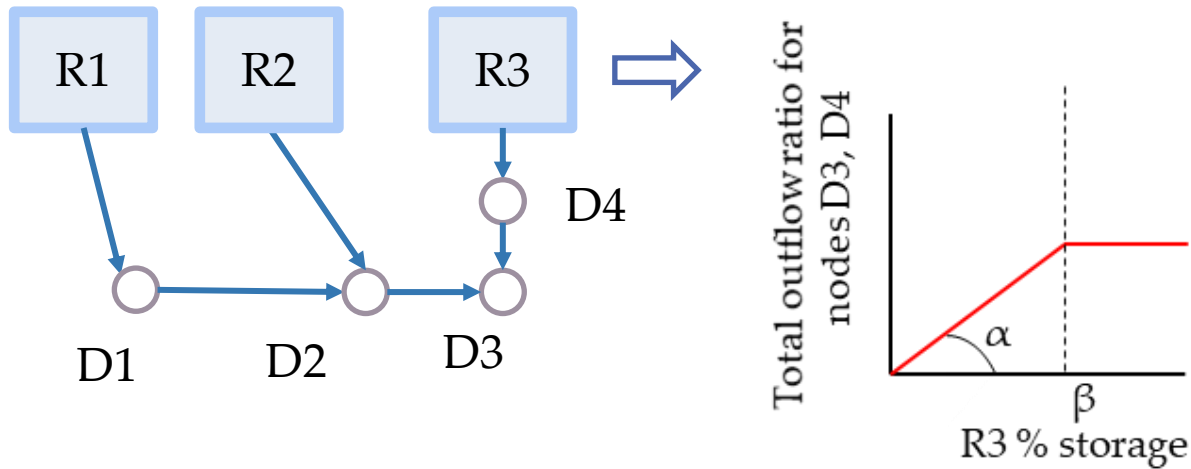
System parameterization

- In previous versions of the DSS, at each time step, and for given inflows and demands, the target releases from reservoirs are estimated on the basis of **parametric operation rules**, using only two control variables per reservoir or groundwater resource (borehole group).
- In Hydronomeas 2020, the rules are also **topology-aware**, which results to more realistic policies, since sources are directly linked with associated demand nodes.
- Another novelty is the **distribution of deficits** across a larger time horizon, based on outflow reduction coefficients according to target priorities and water availability.

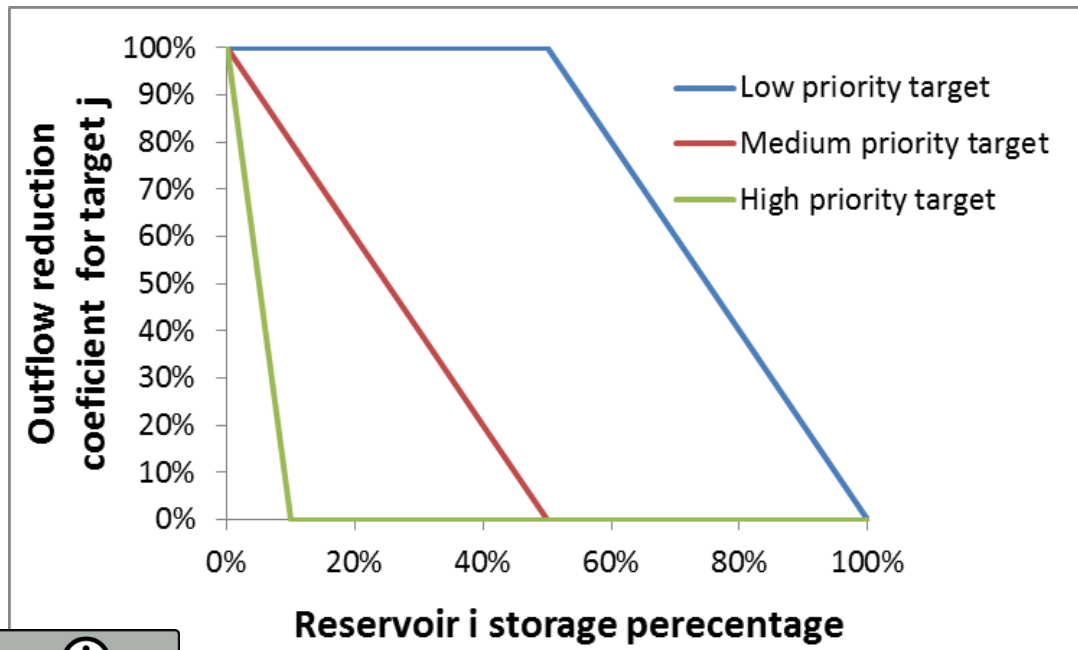


See details in: Nalbantis and Koutsoyiannis, 1997; Koutsoyiannis *et al.*, 2003;

Topology-aware management rules

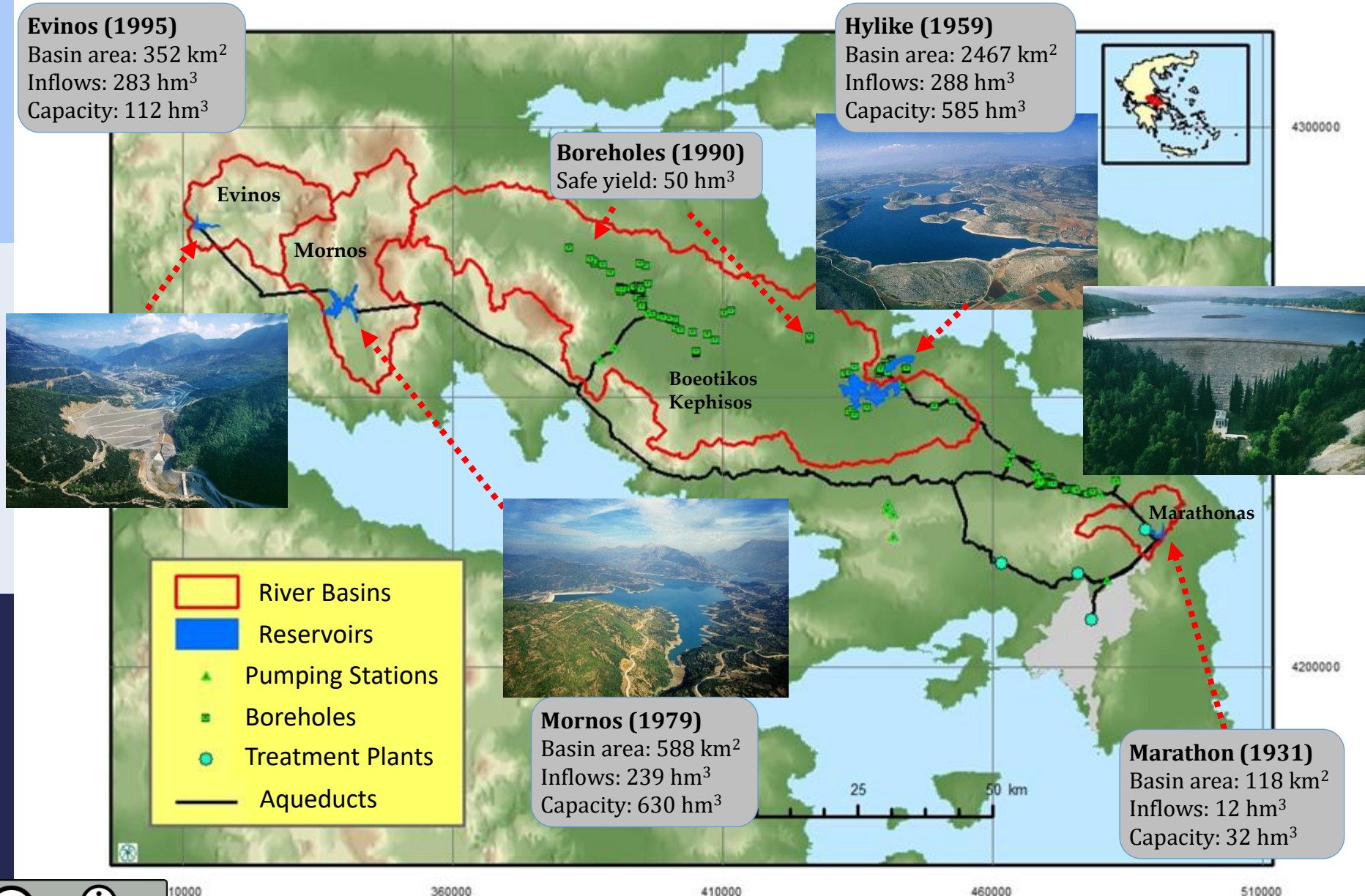


Assignment of target abstractions per source using simple rules, accounting for the sharing of demands



Hierarchical fulfilment of demands and allocation of deficits

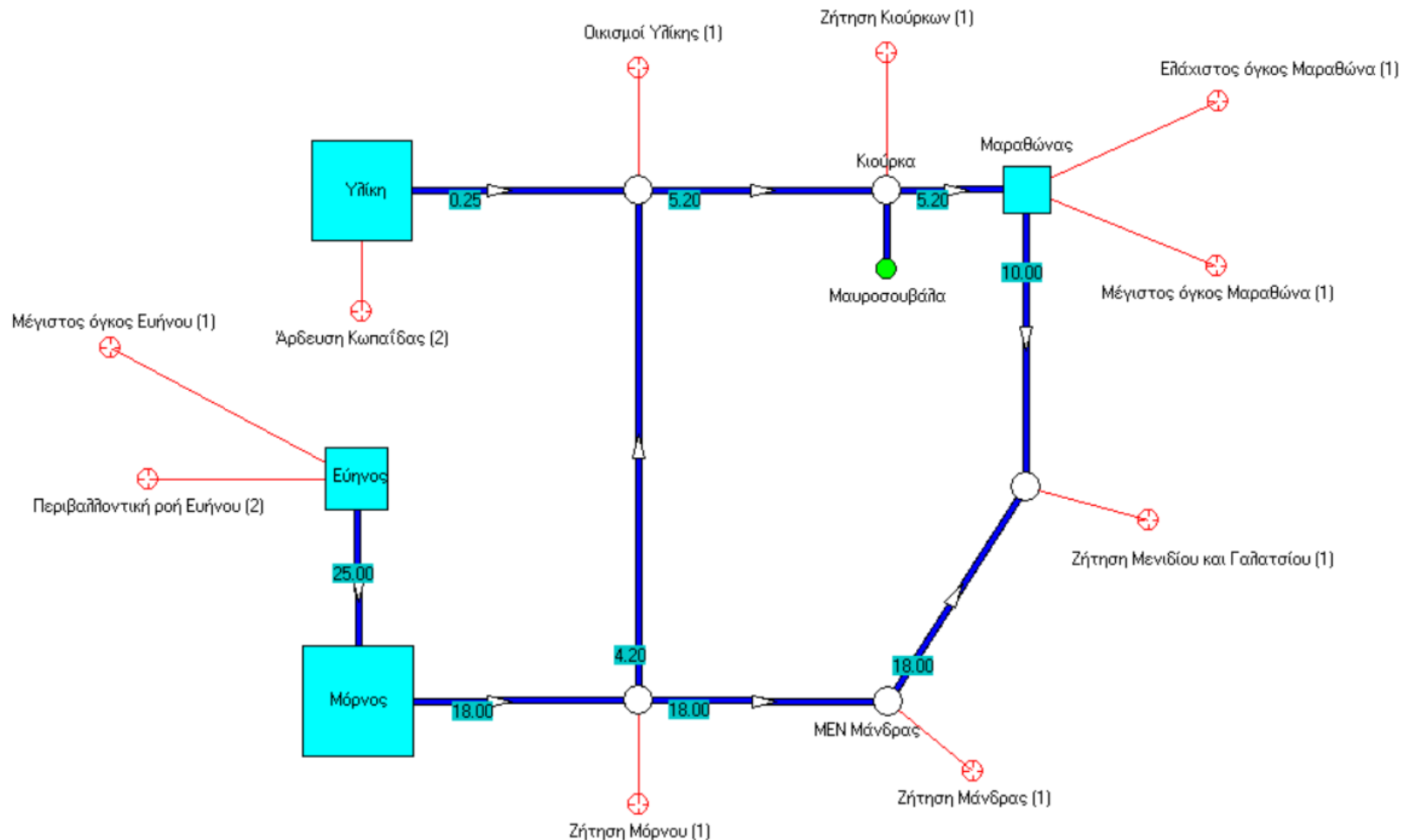
The water supply system of Athens (~4000 km²)



Management challenges and complexity issues

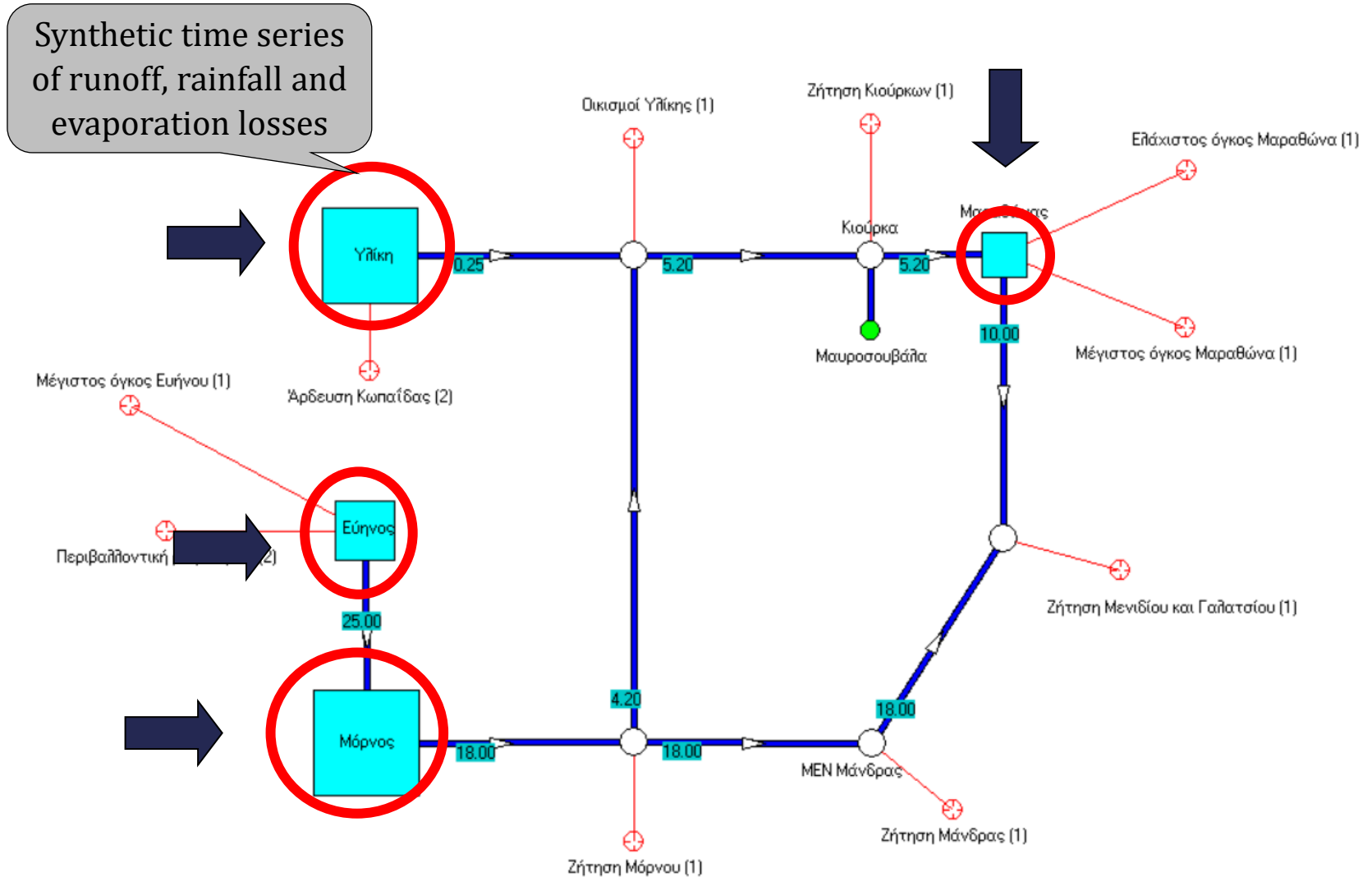
- **Conflicting objectives**
 - Minimization of energy cost
 - Maximization of long-term reliability
- **Multiple water uses**
 - Drinking water to Athens (today $\sim 400 \text{ hm}^3$)
 - Local water uses across the water conveyance network ($\sim 70 \text{ hm}^3$)
 - Environmental flows through Evinos dam (30 hm^3)
- **Multiple sources of uncertainty**
 - Hydroclimatic uncertainty leads to *non-predictable inflows*
 - Uncertain socio-economic conditions result to *uncertain demands*
 - *Uncertain losses* through water transportation and conveyance network
 - *Uncertain technical characteristics of pumps* (capacity, efficiency), resulting in approximate estimation of energy consumption
- Hydronomeas v. 4.9 is used operationally by the water utility EYDAP SA, for the management of its raw water supply system.
- This case study demonstrates the compatibility between the older version and the new Hydronomeas 2020 Python package.

Simplified schematization of the hydrosystem



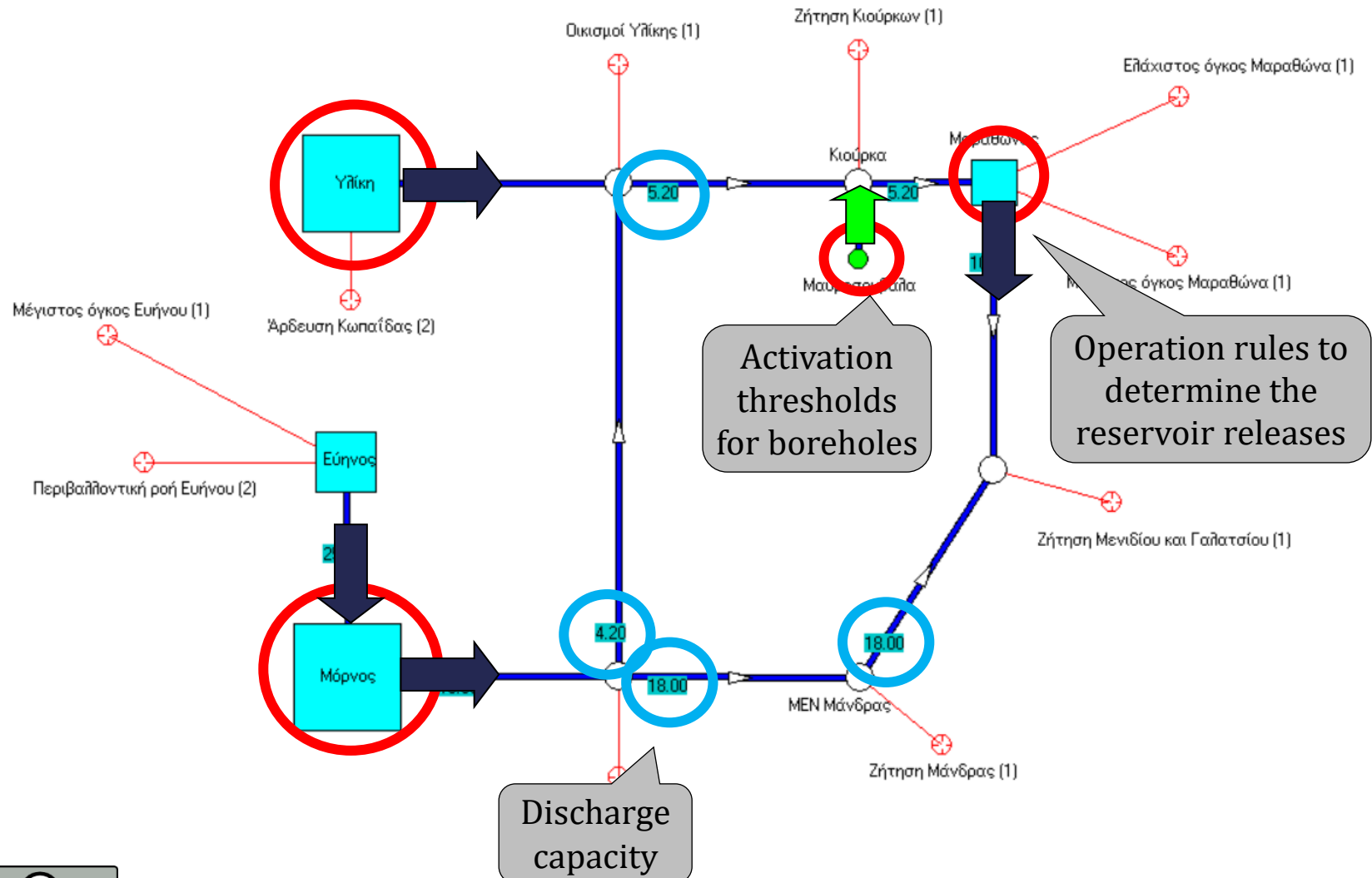
Remark: Representation of the water resource system in the graphical environment of **Hydronomeas v 4.9** here and in the following slides, as currently **Hydronomeas 2020** is **script-based**. Both DSS are used for this case study.

Generation of hydrological inputs

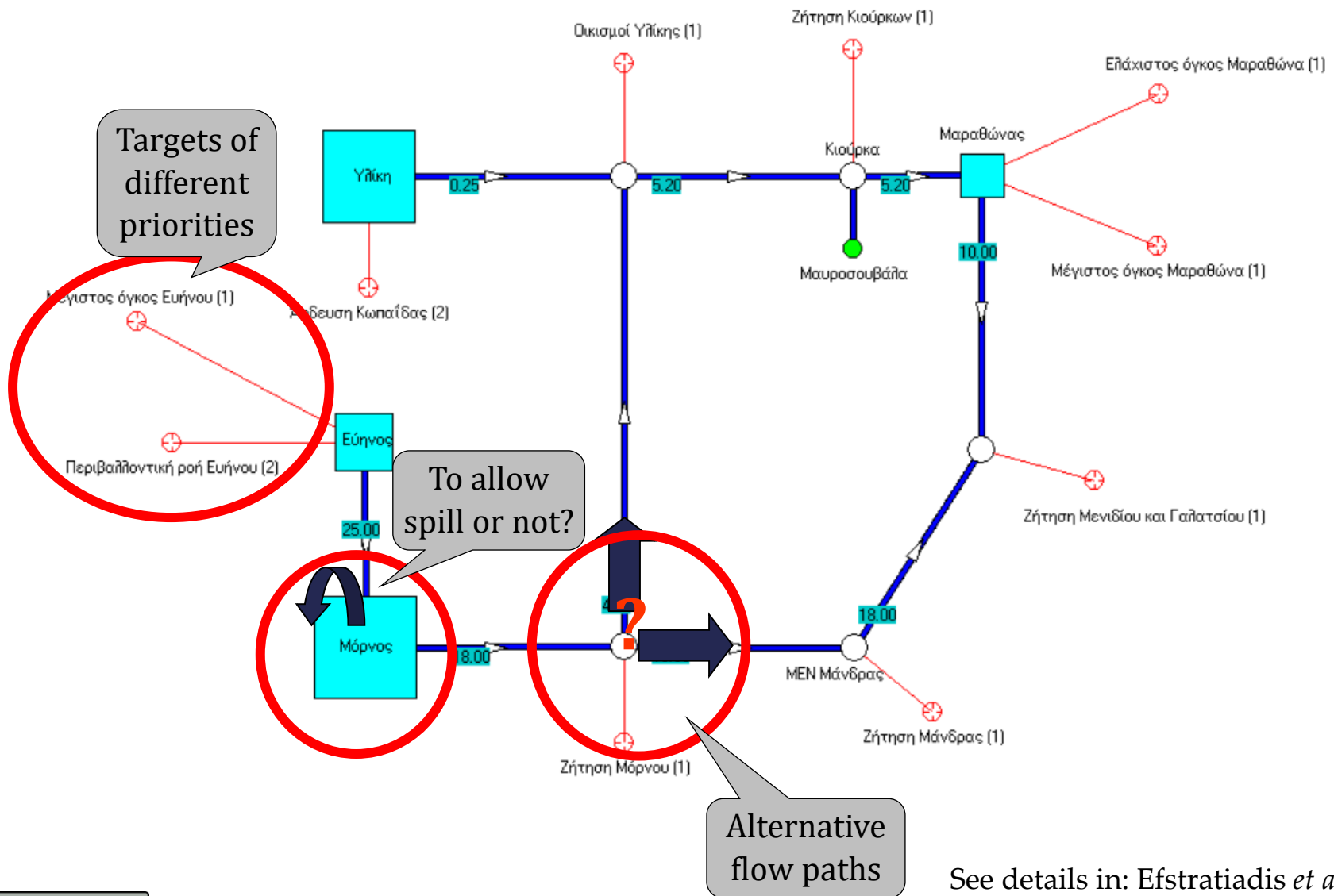


See details in: Efstratiadis *et al.*, 2014

Establishment of the long-term control policy for reservoirs and boreholes



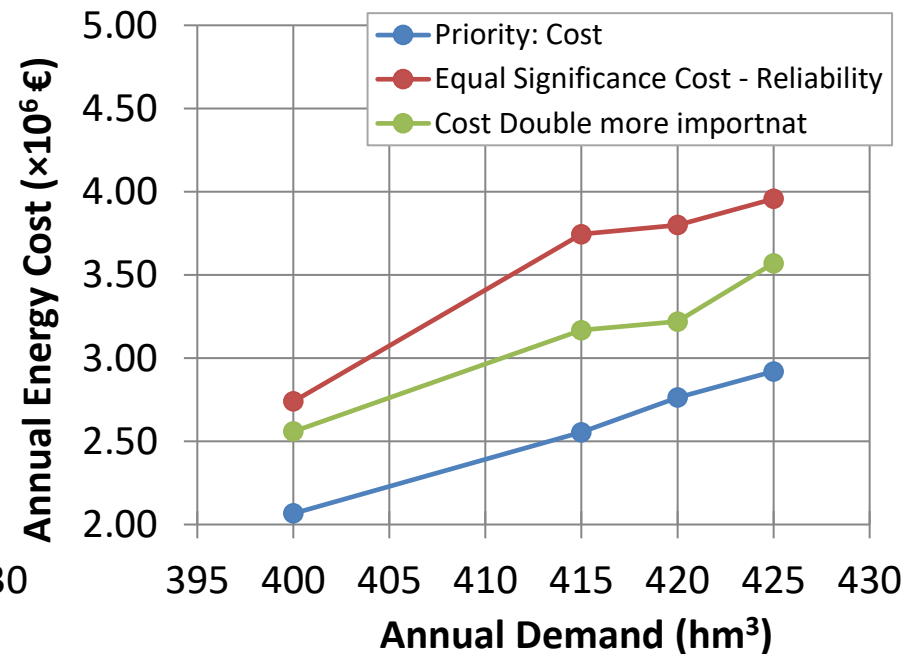
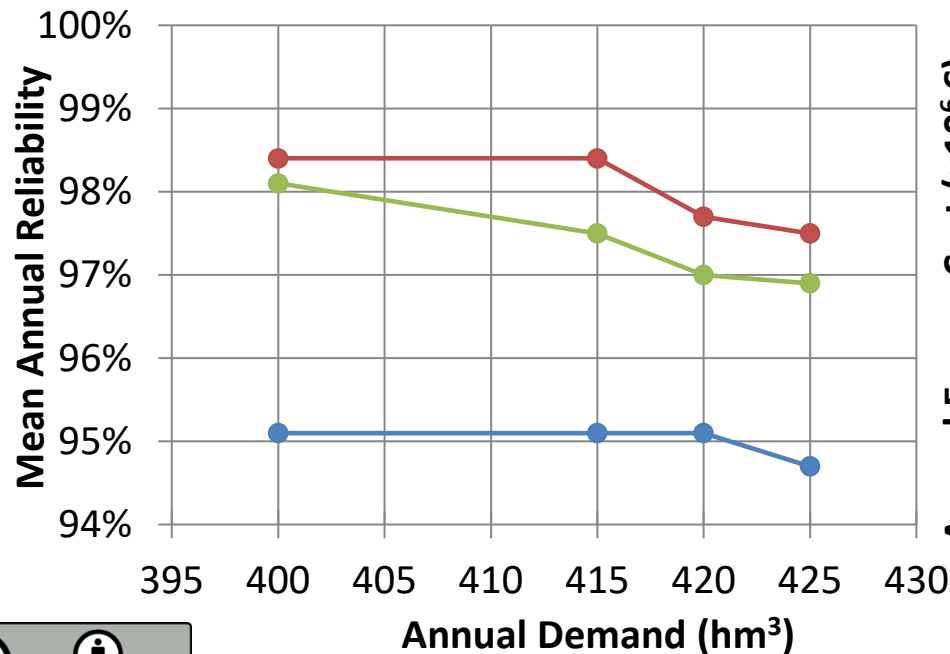
Optimal allocation of actual fluxes



See details in: Efstratiadis *et al.*, 2004

Scenarios & results

- Four annual demand scenarios for broader Athens area: current state (400 hm³) & three future projections (415, 420, 425 hm³).
- Three sets of optimization weights (management policy): Prioritization of cost, equal importance of cost and reliability and cost double more important than reliability.
- Results from the use of the new Hydronomeas 2020 seem robust and aligned with results stemming from the same case study implemented with Hydronomeas v 4.9 (Nikolopoulos *et al.*, 2018).



Roadmap & conclusions

□ Roadmap

- Late 2020: Estimated release of the Python package Hydronomeas 2020
- Late 2021: Estimated release of a new Python-based GUI framework for the package for easier data handling (import/export), network and result visualization, simplified optimization procedures etc.

■ Conclusions

- Hydronomeas 2020 aims to be a full featured open source DSS, provided as a FOSS Python package to the water recourse management community
- Built with well known tools in the scientific community ensures flexibility and future extensibility by other water experts
- Hydronomeas 2020 incorporates state-of-the art methodologies that have been employed in numerous water resources planning and management studies in Greece and operationalized by EYDAP SA in the management of the water supply system of Athens.
- Testing shows full compatibility between the older stand-alone version and the new Python package. Subsequent testing and publications will focus on showcasing the improvements and additional functionality.

References

- Efstratiadis, A., D. Koutsoyiannis, and D. Xenos, Minimizing water cost in the water resource management of Athens, *Urban Water Journal*, 1(1), 3–15, doi:10.1080/15730620410001732099, 2004.
- Efstratiadis, A., Y. Dialynas, S. Kozanis, and D. Koutsoyiannis, A multivariate stochastic model for the generation of synthetic time series at multiple time scales reproducing long-term persistence, *Environmental Modelling and Software*, 62, 139–152, doi:10.1016/j.envsoft.2014.08.017, 2014.
- Koukouvinos, A., D. Nikolopoulos, A. Efstratiadis, A. Tegos, E. Rozos, S.M. Papalexiou, P. Dimitriadis, Y. Markonis, P. Kossieris, H. Tyrallis, G. Karakatsanis, K. Tzouka, A. Christofides, G. Karavokiros, A. Siskos, N. Mamassis, and D. Koutsoyiannis, Integrated water and renewable energy management: the Acheloos-Peneios region case study, *European Geosciences Union General Assembly 2015, Geophysical Research Abstracts, Vol. 17*, Vienna, EGU2015-4912, doi:10.13140/RG.2.2.17726.69440, 2015.
- Koutsoyiannis, D., and A. Economou, Evaluation of the parameterization-simulation-optimization approach for the control of reservoir systems, *Water Resources Research*, 39(6), 1170, doi:10.1029/2003WR002148, 2003.
- Koutsoyiannis, D., G. Karavokiros, A. Efstratiadis, N. Mamassis, A. Koukouvinos, and A. Christofides, A decision support system for the management of the water resource system of Athens, *Physics and Chemistry of the Earth*, 28(14-15), 599–609, doi:10.1016/S1474-7065(03)00106-2, 2003.
- Makropoulos, C., D. Nikolopoulos, L. Palmen, S. Kools, A. Segrave, D. Vries, S. Koop, H. J. van Alphen, E. Vonk, P. van Thienen, E. Rozos, and G. Medema, A resilience assessment method for urban water systems, *Urban Water Journal*, 15(4), 316–328, doi:10.1080/1573062X.2018.1457166, 2018.
- Nalbantis, I., and D. Koutsoyiannis, A parametric rule for planning and management of multiple reservoir systems, *Water Resources Research*, 33(9), 2165–2177, doi:10.1029/97WR01034, 1997.
- Nikolopoulos, D., A. Efstratiadis, G. Karavokiros, N. Mamassis, and C. Makropoulos, Stochastic simulation-optimization framework for energy cost assessment across the water supply system of Athens, *European Geosciences Union General Assembly 2018, Geophysical Research Abstracts, Vol. 20*, Vienna, EGU2018-12290, 2018.
- Nikolopoulos, D., H. J. van Alphen, D. Vries, L. Palmen, S. Koop, P. van Thienen, G. Medema, and C. Makropoulos, Tackling the “new normal”: A resilience assessment method applied to real-world urban water systems, *Water*, 11(2), 330, doi:10.3390/w11020330, 2019.