Investigation and incorporation of water inflow uncertainties through stochastic modelling in a combined optimization methodology for water allocation in Alfeios River (Greece)

E.S. Bekri [(1)(2)], P.C. Yannopoulos[(1)] and M. Disse[(2)],

[(1)] Environmental Engineering Laboratory
Department of Civil Engineering, University of Patras, Greece
University of Patras, Greece, ebekri@upatras.gr

[(2)] Chair of Hydrology and River Basin Management
Faculty of Civil, Geo and Environmental Engineering,
Technische Universität München, Germany

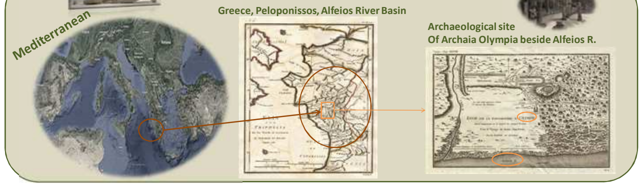
SUMMARY

Alfeios River plays a vital role for Western Peloponnisos (Greece). It forms the longest watercourse and highest streamflow rate representing a significant source of water supply for the region with a complicated puzzle of water users (irrigation, hydropower production, drinking water supply, recreational activities).

A fuzzy-boundary-interval linear programming methodology based on Li et al. (2010) and Bekri et al. (2012) has been adapted and used for optimal water allocation under uncertain and vague system conditions. Uncertainties both of decision variables and coefficients of the objective function and constraints were expressed either as fuzzy or intervals and solved through associated α-cut levels.

In the present study, the uncertainty of the monthly water inflows is incorporated by generating stochastically synthetic time-series based both on historical data and projected climate change conditions.

HISTORICAL IMPORTANCE OF ALFEIOS BASIN



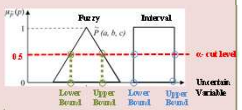
AIMS

The goal of this study is to analyze and incorporate the **critical uncertain parameter of water inflows** as an additional type of uncertainty in the suggested methodology, in order to enable the assessment of optimal water allocation for hydrologic and socio-economic scenarios based on stochastic simulation of both historical data and expected climate change.

PROPOSED METHODOLOGY

Fuzzy-boundary interval - stochastic programming (Li et al., 2010):

- **Aim:** Identification of **optimal water allocation** target with minimised risk of economic penalty from water shortage (water demand) and opportunity loss from spill water volumes
- Linear optimization process
- Uncertain variables: (a) favourable (X_{ij}^{+}); (b) unfavourable (X_{ij}^{-})

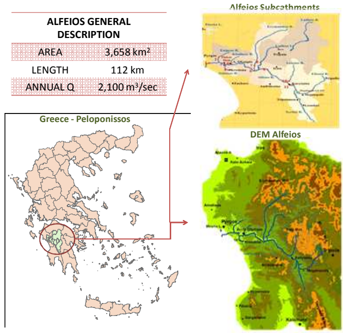


- Two solution methods:
  1. "Risk-Prone" or "Optimistic" (**best -case model**)
  2. "Risk-adverse" or "Pessimistic" (**worst -case model**)
- Based on discretization of membership grade into α-cut levels (0, 1)
- Solving for each solution type and α-cut level: 2^n deterministic submodels for all combinations of lower & upper bound value for *n* fuzzy/interval variables
- For each solution type: $f^{\alpha}_{opt} = \{f^{\alpha}_{min}, f^{\alpha}_{max}\}$,

  where $f^{\alpha}_{min} = \min\{f_1, f_2, .., f_2^n\}$ $\quad f^{\alpha}_{max} = \max\{f_1, f_2, .., f_2^n\}$

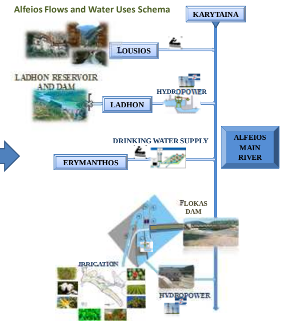
ALFEIOS RIVER BASIN

ALFEIOS GENERAL DESCRIPTION	
AREA	3,658 km²
LENGTH	112 km
ANNUAL Q	2,100 m³/sec



LADHON – RESERVOIR - DAM:
- Gross - usable storage: 57.6 - 46.2 hm³
- Main purposes: Irrigation & Hydropower
- Monthly operational curve (target reservoir level)

LADHON – HYDROPOWER STATION:
- ~8 km downstream from Ladhon Dam
- Purpose: Satisfy peak energy demand
- Total max capacity: 70 MW
- Primary-Total Mean Annual Energy: 173-340 GWh



FLOKAS – DAM:
- Diversion dam for irrigation purposes
- 16 km from Kyparissiakos Gulf coastline
- 97% of Alfeios catchment

SMALL HYDROPOWER STATION:
- Max power capacity: 6.6 MW
- Available head: 10m

FLOKAS – IRRIGATION CANAL:
- Present irrigated area: 50-60% Total irrigable area (12,250 ha)
- Irrigation period: Mid April to Mid October
- Crop pattern: Cotton, corn, alfalfa, watermelons, citrus
- Surface and drip irrigation

KARYTAINA	
AREA	783.05 km²
MEAN ELEV.	759 m
MEAN INCLIN.	17.8 %

LOUSIOS	
AREA	159.34 km²
MEAN ELEV.	1082 m
MEAN INCLIN.	24 %

LADHON	
AREA	1123.66 km²
MEAN ELEV.	858 m
MEAN INCLIN.	27.2%

ERYMANTHOS	
AREA	360.10 km²
MEAN ELEV.	861 m
MEAN INCLIN.	35.5 %

OPTIMISATION PROBLEM

OBJECTIVE FUNCTION Maximise Total Benefit = **Weight1 × (Benefit(HPLadhon) - Penalty(SpillLadhon)) + Weight2 × (Benefit(Irrigation+Extra) – Penalty(IrrigationShortage)) + Weight3 × (Benefit(HPFlokas) - Penalty(SpillFlokas))**

CONSTRAINTS

LADHON
- Water Volume Mass Balance
- Min & Max pumping capacity
- Min & Max reservoir capacity
- Evaporation: linear F(average reservoir storage(t))

FLOKAS
- Water Volume Mass Balance
- Min & Max pumping capacity
- Fish ladder flows
- Min environmental flows

UNCERTAINTIES

Variable Name	Uncertainty Type	Variable Effect
Unit Benefit HP Ladhon (€/MWh)	Fuzzy: LB (40, 50, 55), UB (60, 65, 75)	Favourable
Unit Benefit HP Flokas (€/MWh)	Interval: (80, 87.75)	-
Unit Benefit Irrigation Flokas (€/m³)	Interval: LB (0.19, 0.2), UB (0.24, 0.26)	Favourable
Unit Penalty HP Ladhon (€/MWh)	Fuzzy: LB (90, 115), LB (0.19, 0.2)	Unfavourable
Unit Penalty HP Flokas (€/MWh)	Interval: (120, 130)	-
Unit Penalty Irrigation Flokas (€/m³)	Fuzzy: UB (0.29, 0.31), LB (0.36, 0.39)	Unfavourable
Conversion Factor of Flokas (%)	Interval: (1, 1.079)	Favourable

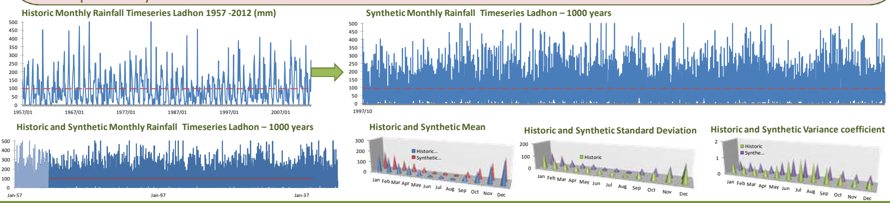
WATER INFLOW UNCERTAINTY – STOCHASTIC SIMULATION

APPROACH

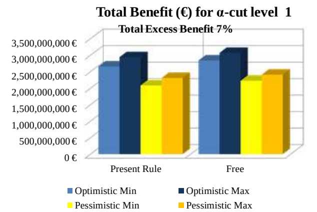
1st Step: Collection, analysis and correction of temperature and rainfall timeseries at 4 main subcatchments: (a) Karytaina, (b) Lousios, (c)Ladhon and (d)Erymanthos

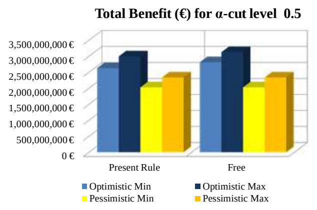
2nd Step: Hydrologic simulation using lumped conceptual water balanced model ZYGOS (ITIA, NTUA)

3rd Step: Stochastic simulation for the Alfeios river system using Symmetric Moving Average (SMA) model of an original two-level multivariate scheme CASTALIA (Koutsogiannis and Efstratiadis, 2001) for simultaneous generation at the four subcatchments of timeseries of 1000 years, appropriate for preserving the most important statistics of the historical time series and reproducing characteristic peculiarities of hydrological processes such as long-term persistence, periodicity and skewness



OPTIMISATION RESULTS WITH STOCHASTIC WATER INFLOWS





CONCLUSIONS

- Flexible & efficient incorporation of uncertainties (intervals, fuzzy and stochastic) in linear optimisation process through α-cut levels, providing a clear & comprehensive interpretation of uncertain variable values at each stage
- Assessment & comparison of total benefit range of various water allocation pattern for a risk-prone and risk-adverse attitudes of decision makers

REFERENCES

1. Li, Y.P., Huang, G.H. and S.L., Nie, (2010), Planning water resources management systems using a fuzzy boundary interval-stochastic programming method, Elsevier Ltd, Advances in Water Resources, 33: 1105–1117, doi:10.1016/j.advwatres.2010.06.015.
2. Bekri, E.S., Disse, M. and P.C.,Yannopoulos, (2012), Methodological framework for correction of quick river discharge measurements using quality characteristics, Session of Environmental Hydraulics – Hydrodynamics, 2nd Common Conference of Hellenic Hydrotechnical Association and Greek Committee for Water Resources Management, Volume: 546-557 (in Greek) .
3. Bekri, E. and P. Yannopoulos (2012). "The Interplay Between the Alfeios (Greece) River Basin Components and the Exerted Environmental Stresses: a Critical Review." Water, Air, & Soil Pollution 223(7): 3783-3806.

ACKNOWLEDGMENTS

European Union European Social Fund. OPERATIONAL PROGRAMME EDUCATION AND LIFELONG LEARNING investing in knowledge society. MANAGING AUTHORITY. NSRF 2007-2013. Co-financed by Greece and the European Union

The present work is supported by HYDROCRITES University Network. For further details visit http://www.hydrocrites.upatras.gr