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Assessment of environmental flows of Acheloos Delta

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1. Abstract

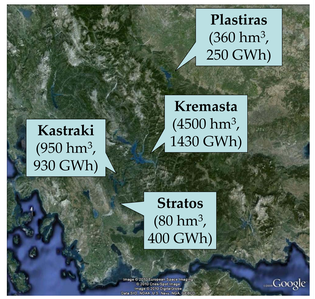
Acheloos, the river with the highest discharge among rivers of Greece, has four hydroelectric dams, while two more dams are under construction. In addition, there are plans for partial diversion of the river to a nearby water district, for irrigation and hydroelectric development. The Acheloos Delta is considered to be one of the most significant Mediterranean wetland habitats for its ecological importance, including fish fauna.

The objective of this case study was to redefine the ecological flow and propose an outflow management policy from the most downstream reservoir (Stratos), in order to preserve the ecosystem at the Acheloos Delta. A hydrological analysis is employed to reconstruct the natural discharge records along the river on a daily basis, accompanied by a detailed evaluation of alternative methodologies for the estimation of the ecological flow.

Based on the results of the analyses, the corresponding water management policy is determined, taking into account the characteristics of the hydropower plan and the related hydraulic works.

2. The river Acheloos water resource system

- The river with the highest mean annual flow (137 m^3/s).
- Four hydroelectric dams (Plastiras, Kremasta, Kastraki, Stratos), serving multiple uses (irrigation, water supply, flood control, ecotourism).
- Two more hydroelectric dams and a tunnel are under construction, for the diversion of 600 000 m^3/yr for irrigation and environmental restoration of the nearby Thessaly plain.
- This is the first system in Greece that has been studied under combined hydrological, environmental and energy criteria (Hydroexygiantiki, 1995; Koutsoyiannis, 1996).



Study area and characteristic data for the four hydroelectric dams (total storage capacity, mean annual power production), operated by the Public Power Corporation (PPC)

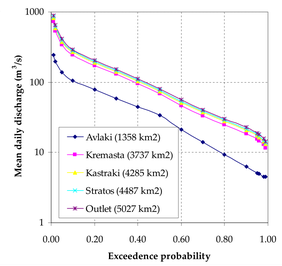
3. Environmental value of Acheloos Delta

- Protected by the Ramsar convention.
- Great vegetation riparian zone (trees rising 15 m.).
- 41 species of fish fauna (four endangered, e.g. *Acipencer sturio).*
- 259 species of birds (*Fulica atra*, *Larus Genei*, *Egretta alba*, *Phalacrocorax Carbo*, *Aythya ferina*, *Anas Penelope*), including migrant.
- 20 species of reptile.

The regulation of flows through the Stratos dam protects the downstream areas against flood hazards; yet, during the last decades, the flood zone of the river was (illegally) occupied for irrigation purposes.

4. Hydrological data and analysis

- Estimation of naturalized daily flows downstream of the dams and in the river estuary (1966-2008) and construction of flow-duration curves.
- Available data: (a) flow measurements at Avlaki station (~1/3 of total basin area), and (b) reservoir level and outflow data, on a daily basis.
- Initial approaches based on the daily water balance of Kremasta reservoir (the largest in Greece), using only storage and outflow data, resulted to unreliable estimates, i.e. too low flows during the summer.
- The daily flows were corrected to account for rainfall and losses due to evaporation and leakage; thus the mean discharge of August increased from 13.6 to 25.0 m^3/s.
- Due to the lack of hydrometric data, the runoff of the lower basin (between the Stratos dam and the estuaries) was estimated using an elementary regional model.



5. Review of Environmental Flow Models (EFM)

- There exist 207 methods applied in 44 countries, which can be classified in four main categories (Tharme, 2003):
  1. **Hydrological methods** (30% of total applications) use naturalized historical discharge series (daily or monthly), for making flow rate recommendations on the basis of statistical criteria (e.g., Texas Method, Tennant, Flow Duration Curve);
  2. **Hydraulic rating** (11% of total applications) use changes in simple hydraulic variables (wetted perimeter, maximum depth);
  3. **Habitat simulation** (28% of total applications) represent physical microhabitat with a combined hydraulic/biologic model (IFIM);
  4. **Holistic methodologies** (7.7% of total applications) are multi-criteria methods, accounting for ecological, geomorphological, water quality and other objectives (e.g., DRIFT, BBM).
- EFMs have not been incorporated in the Greek institutional framework.
- Normal practice is based on simplified hydrological approaches (mainly due to the lack of field measurements), resulting in the establishment of a constant minimum ecological discharge.

6. Results for simplified hydrological methods

- The Table presents the estimated environmental flows downstream of Stratos with the approaches used in various countries; these are deemed to be applied year-round.
- The minimum value (3.4 m^3/s) is estimated according to the French Freshwater Fishing Law (June 1984), which requires that the residual flows in diverted sections of a river must be at least 1/40th of the mean flow for existing schemes and 1/10 of the mean flow for new ones (Acreman *et al.*, 2008).
- The steady-discharge approach of most of the hydrology-based methods fails to preserve many important eco-hydrological characteristics of the river, related to the seasonality of flows, the flood events, etc.

Country	Discharge (m^3/s)
Spain	13.7-27.5
Italy	13.7
Ireland	1.4 -13.7
UK	18.9
Austria	28.8
Germany	41.2 - 82.4
Canada	34.4
France	3.4 (existing dams) - 13.7 (new dams)
Portugal	3.4 - 6.9

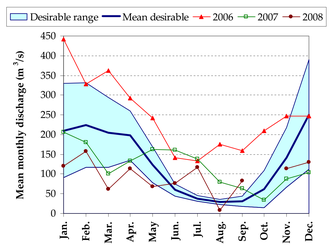
Note: The minimum mean monthly naturalized flow downstream of the Stratos reservoir is 29.0 m^3/s in August.

7. Range of Variability Approach (RVA)

- The RVA identifies annual river management targets based upon a comprehensive statistical characterization of ecologically-relevant flow regime characteristics (Richter *et al.*, 1996).
- One of the most sophisticated hydrological methods, since it links simple hydrological data with basic ecological-environmental indices.
- Input data is mean daily discharge of 20-year time series (at least).
- The natural range of streamflow variation is characterized using a suite of 32 ecologically-relevant statistical parameters (e.g., mean monthly discharge, characteristic percentiles, maximum and minimum values, duration of extremes, etc.).
- Thirty-two management targets, by means of flow constraints, one for each of the 32 IHA parameters, are selected.
- The model exports management guidelines for every parameter.
- Its advantage is the flexibility (plurality of management targets) and the adaptation to the seasonal variability of runoff (in contrast to simplest approaches imposing a single minimum flow to preserve).
- The USGS provides a web-based application, in addition to observed flow data all over America.

8. Results and discussion of RVA

- The method provides a desirable range of monthly outflows through the Stratos reservoir, which is, in general, feasible to follow.
- Yet, the outflow constraints introduce significant complexity regarding the combined operation of the three hydroelectric reservoirs.
- A pilot management plan, in addition to a systematic monitoring program for each environmental component, is essential, to evaluate alternative policies and finally establish suitable operation rules.
- The implementation of the proposed operation policy requires also an agreement between all involved stakeholders (PPC, farmers and local authorities).



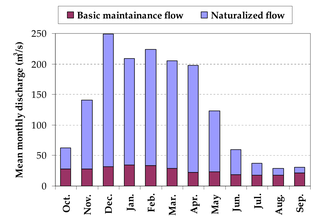
Actual release policies from the Stratos dam (2006, 2007, 2008) vs. desirable flow limits, estimated through the RVA method.

9. Basic Maintenance Flow (BMF) method

- The methodology was developed in Spain and applied to the Ebro river, since 1996 (Palau and Alcazar, 1996).
- It belongs to the advanced hydrological-environmental models, which has been gradually improved to date (Alcazar *et al.*, 2008).
- The method is based on two key principles:
  - habitats adjust to seasonal hydrological changes;
  - the baseflow for a specific time horizon is the minimum limit for their survival.
- The method aims to define the average magnitude and duration of low flows, using 100-day moving average time series.
- The final objective is to establish a basic maintenance flow, which is calculated by multiplying the baseflow with a monthly coefficient that accounts for the seasonal variability.
- For sensitive ecosystems, artificial flood discharges are foreseen, taking also into account a mean daily flood discharge, which is estimated using the Gumbel distribution for return periods of 5-7 years; this flooding is essential for sedimentation transport, the refreshment of water and the preservation of the downstream ecosystem.

10. Results and discussion for BMF

- Given that the hydro-climatic conditions of Spain and Greece are similar, and taking also into account its parsimony, the method seems the most suitable for the Acheloos case study.
- The minimum required steady baseflow in the estuaries is 14.1 m^3/s.
- The basic maintenance flow in the estuaries varies from a mean monthly flow of 17.8 (July) to 34.7 m^3/s (January), following the variability of the naturalized flows.
- The operation of the hydroelectric plant in Stratos can be adapted to the above flow constraints.
- The PPC is reviewing these recommendations in view of the requirements for power generation from Stratos and the other upstream hydroelectric plants, as well as the ensuing financial consequences of their application.



11. Conclusions

- The common approaches assuming a constant minimum ecological flow are not suitable for the Mediterranean hydroclimatic conditions, since they do not account for the significant variability of runoff.
- The RVA model is well adapted to the variability of flows; however it results to complex release policies, which are difficult to apply in multi-reservoir hydropower systems.
- The BMF approach is more parsimonious; it imposes a lower limit for the monthly releases as well as once-per-year artificial flooding.
- There are many open issues before establishing a suitable environmental policy along the Acheloos river and its estuaries, including:
  - a comprehensive hydrological study for the heavily modified lower basin of Acheloos, validated on the basis of observed discharge data;
  - a realistic assessment of the environmental parameters, based on hydrological, hydraulic, water quality and biological data;
  - an optimization of the overall water resource system, under multiple water uses and constraints;
  - a monitoring program to control the implementation of the proposed operation policy in real-time.

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