Flood control across hydropower dams: The value of safety

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Hydroelectric dams with a gated spillway

**Advantages**
- Increased storage capacity
- Increased head
- Flexibility in water-energy management

**Disadvantages**
- Subject to human manipulations under stressed conditions
- Too early opening → hydrodynamic losses
- Too late opening → risk of dam overtopping

Safety

Economy
Pournari Dam, Arachthos River, Epirus, Greece

Why this case study?
- One of the largest hydroelectric works of Greece (300 MW)
- Located just upstream of Arta (25000 residents)

- Earth dam (1978)
- Dam height: 107 m
- Upstream drainage area: 1794 km²
- Spillway width: 37.5 m (3 x 12.5 m)
- Spillway capacity: 6100 m³/s
- Turbine capacity: 500 m³/s

Historical bridge of Arta, 17th century (Source: Wikipedia)
Typical section and characteristic levels

Spillway crest: +107.5 m
Top of gates: +120.0 m
Max. flood level: +125.5 m
Dam crest: +127.0 m

Storage capacity increased from 505 to 885 hm³
Flood management concept

Regarding turbines operation:

- \( z \geq z_{e_0} \rightarrow \text{Emergency} \rightarrow \text{Maximum capacity} \)
- \( z \leq z_{e_c} \rightarrow \text{Normal} \rightarrow \text{Standard energy production schedule} \)

Regarding the gate control:

- Progressive opening of gates \( \rightarrow \) release of specific ratio \( a_k \) of spillway capacity
- \( z_0^n \rightarrow \text{threshold for full gate opening} \)
- \( z_c \rightarrow \text{threshold for closure of all gates} \)
Simulation

**Inputs**
- Geometrical, hydraulic and hydrodynamic properties of system elements (reservoir, spillway, gates, turbines)
- Inflow hydrograph
- Power production schedule (normal mode)
- Operational rules of gates and turbines

**Outputs**
- Simulated timeseries (reservoir stage, outflow from spillway & turbines, power production)
- Performance metrics (safety and economy)
Performance metrics to optimize

<table>
<thead>
<tr>
<th>Aspects of safety</th>
<th>Criteria</th>
<th>Quantification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection of dam and associated infrastructures</td>
<td>Distance of max. reservoir stage from characteristic levels (dam crest, MFL)</td>
<td></td>
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<tr>
<td>Minimize flood risk of downstream floodplains</td>
<td>Maximum outflow through the spillway system (ratio of its discharge capacity)</td>
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<tr>
<td>Loss of storage due to gate opening</td>
<td>Potential energy to be produced by the overflowing water</td>
<td></td>
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<tr>
<td>Turbine operation in contrast to their schedule</td>
<td>Deviation of actual vs target power production (small penalty)</td>
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Setting up optimization

Control variables - Parameters
- Turbine control thresholds
- Gate opening thresholds
- Spillway capacity ratios
- Gate closure threshold

Multiobjective function
- Performance metrics
- Weighting coefficients (economy vs safety)

Scenario based approach
- Inflow hydrographs
- Initial reservoir conditions
The case of Pournari Dam

- Synthetic hydrographs for characteristic return periods (5, 10, 50, 100 years)
- Power plant scheduling:
  8:00-12:00 a.m. & 18:00-22:00 p.m. → 500 m³/s (max capacity, peak hours)

Alarm stage of dam operator (PPC): +118.0 m

- +119.20 m
  Gate opening: 100%

- +118.45 m
  Gate opening: 17.7%
  Turbines: Emergency
  Gate opening: 3.3%

- +117.84 m
  Turbines: Normal

- +117.65 m
  Gate closure
Floods of 2005 & 2015: Actual vs theoretical stage management

28/12/2005 - 1/1/2006

30/1/2015 - 2/2/2015
### Summary data

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<thead>
<tr>
<th></th>
<th>2005</th>
<th>2015</th>
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<tbody>
<tr>
<td>Accumulated inflow (hm³)</td>
<td>222</td>
<td>262</td>
</tr>
<tr>
<td>Maximum observed inflow (m³/s)</td>
<td>1712</td>
<td>2095</td>
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<tr>
<td>Initial reservoir level (m)</td>
<td>+115.5</td>
<td>+111.8</td>
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**Actual operation (PPC policy)**

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<tr>
<td>Maximum reservoir level (m)</td>
<td>+116.8</td>
<td>+119.6</td>
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<tr>
<td>Loss of energy (GWh)</td>
<td>12.0</td>
<td>6.4</td>
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**Theoretical operation (optimized rules)**

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<tr>
<td>Maximum reservoir level (m)</td>
<td>+118.2</td>
<td>+119.7</td>
</tr>
<tr>
<td>Loss of energy (GWh)</td>
<td>3.3</td>
<td>1.0</td>
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</table>

Dealing with Flood Events at Hydroelectric Plant areas in Western Greece, Roilos C.
Conclusions & perspectives

1. Generic simulation-optimization method for establishing effective rules for the conjunctive control of turbines and gates during severe flood events
2. Control policy expressed in terms of level thresholds and discharge ratios
3. Multiobjective approach against multiple flood hydrographs to ensure equilibrium between safety and economy goals
4. Key advantages
   - Minimal and easily retrieved real-time data (reservoir stage)
   - Easily formalized in Monte-Carlo setting (stochastically generated flood events and reservoir states)
5. Potential improvements
   - real-time monitoring data over the upstream river basin
   - short-term hydrometeorological forecasting products
Thank you for your attention