Reservoirs – water consumers or collectors?

&

The effects of change in climate and irrigation practice on the hydropower resources in Kizilirmak River Basin, Turkey

Tor Haakon Bakken, NTNU
Water consumption - what raised the attention?


- What is the potential for renewable sources to replace fossil-based fuels?

- The different technologies benchmarked with respect to various criteria, including ‘water needed to produced 1 MWh electricity’ (water consumption)
Water consumption from energy generation:
**Source:** IPCC SRREN, 2011

Wide range between minimum and maximum of estimates

- 209 m$^3$/MWh
- ~0 m$^3$/MWh
IPCC SRREN (2011) states

- Upper values for hydropower result from few studies measuring gross evaporation values, and may not be representative.

- Research may be needed to determine the net effect of reservoir construction on the evaporation in the specific watershed.

- Allocation schemes for determining water consumption from various reservoir uses in the case of multipurpose reservoirs can significantly influence reported water consumption values.
ISO 14046 Water Footprint

Might affect the energy sector in a similar way as carbon footprint assessments
On-going scientific debate

• Bakken et al. (2013) claims the methodological framework is immature and presents a biased picture. Has received support from e.g. Demeke et al. (2013), Chenoweth et al. (2014).

• ‘LCA-based scientific communities’ claim hydropower production is globally a large water consumer, e.g. Gerbens-Lenes (2009), Mekonnen and Hoekstra (2012).

• High water consumption values can be observed in water-stressed regions, but this is also where the reservoirs are most needed (Weichert, 2013).

• Reservoirs are needed to mitigate the effects of climate change on the water resources (e.g. IPCC, 2008)
ICOLD-database

Contains information on a large number of dams > 15 meters

Holds information such as installed capacity, energy production, dam characteristics, country of location and purpose
  • single versus multi
  • main purpose
  • secondary purpose

Non-complete in terms of properties

Other sources estimate the total number of dams > 15 meters to be around 45 000 world-wide (ICOLD-web: ~ 50 000)

n=39188 by June, 2014
n=39064 for our study
Overview of purposes

Approx. 75% of the reservoirs are single purpose

The most frequent purpose: Irrigation

The second most frequent purpose: Hydropower

Source: ICOLD database
~ 45 % of single-purpose reservoirs are for irrigation

~ 20 % of single-purpose reservoirs are for hydropower

Source: ICOLD database
Irrigation, flood control, hydropower and water supply are all common functions.
Reservoirs summed up

The majority of reservoirs are single (75%) and irrigation is the dominating purpose. Irrigation, flood control, hydropower and water supply are all common functions of multipurpose reservoirs. Very few reservoirs with single or main purpose hydropower are located in water-scarce regions.
Study of water management and the role of reservoirs in Turkey
Case study Kizilirmak River Basin, Turkey
Kizilirmak River Basin
Concerns

How much water will be available for power production in the near and long-term future?

- Climate change and the effects on water
- Land use changes/irrigation practice
Monthly water flows

EIE 1533 (İnözü gauging station)
Mean monthly discharge between 1961 and 1989

EIE 1503 (Yahsihan gauging station)
Mean monthly discharge between 1939 and 1986

EIE 1501 (Yamula gauging station)
Mean monthly discharge between 1970 and 2000

EIE 1535 (Sögoüûhan gauging station)
Mean monthly discharge between 1963 and 2008
Missed years: 1970 and 1969
Plans for irrigation
Model setup (WEAP)
## Scenario definition

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Temperature Summer/Winter</th>
<th>Precipitation Summer/Winter</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1A ('year 2050')</td>
<td>+2.5 / +1.5</td>
<td>-5% / -2.5%</td>
<td>No additional</td>
</tr>
<tr>
<td>Scenario 1B ('year 2050')</td>
<td>+2.5 / +1.5</td>
<td>-5% / -2.5%</td>
<td>Increased</td>
</tr>
<tr>
<td>Scenario 2A ('year 2090')</td>
<td>+3 / +2</td>
<td>-10% / -5%</td>
<td>No additional</td>
</tr>
<tr>
<td>Scenario 2B ('year 2090')</td>
<td>+3 / +2</td>
<td>-10% / -5%</td>
<td>Increased</td>
</tr>
<tr>
<td>Scenario 3 ('year 2090')</td>
<td>+3 / +2</td>
<td>-10% / -5%</td>
<td>Increased</td>
</tr>
</tbody>
</table>

Source: IPCC, 2013: Annex I
Illustration – sensitivity to climate change

- Assessed at outlet of basin
- Base-line based on historical monitoring data
- Base-line different than base-line in the WEAP-results
- Simplistic calculation

Volumes [m$^3$/sec]

<table>
<thead>
<tr>
<th></th>
<th>Prec</th>
<th>Evapo and Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol</td>
<td>1114.7</td>
<td>928.7</td>
</tr>
<tr>
<td>Prec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evapo</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Precipitation
- Run-off
- Evaporation
Illustration – sensitivity to climate change

- Precipitation
- Run-off
- Evaporation

Volumes [m$^3$/sec]

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Precipitation</th>
<th>Run-off</th>
<th>Evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base-line</td>
<td>1115</td>
<td>186</td>
<td>929</td>
</tr>
<tr>
<td>P = -5 % and no change evaporation</td>
<td>1059</td>
<td>130</td>
<td>929</td>
</tr>
<tr>
<td>P = -5 % and evaporation + 3%</td>
<td>1059</td>
<td>102</td>
<td>957</td>
</tr>
<tr>
<td>P = -10 % and evaporation + 3%</td>
<td>1003</td>
<td>47</td>
<td>957</td>
</tr>
</tbody>
</table>
Conclusions

- There is clear competition over water between hydropower production and irrigation in Kizilirmak River Basin, Turkey.
- The effect of climate change and irrigation will reduce the available water resources for hydropower production significantly. Similar trends found also by e.g. Milly et al. (2005), IPCC (2008), Maestre-Valero et al. (2013).
- The effect of climate change is stronger than the effect of continuous withdrawal/consumption in the agricultural sector in parts of the basin.
- Small changes in climate will potentially make big changes in runoff when low runoff coefficients (low effective rainfall/high evaporation).
- Integrated assessment of the water resources needed in order to plan the mid- and long-term hydropower resources/production.
- The risk profile of the investment portfolio is to a large extent affected by the location of the HP prospect compared to other water users.
If hydropower is a water consumer or not?

- The purpose of the reservoir must be investigated
- Allocation needed in case of multipurpose use
- NET effect important
- Investigate the tradeoff between the increased availability of the net loss of water due to evaporation
Are reservoirs water consumers or water collectors?  
Reflections on the water footprint concept applied on reservoirs

Authors: T.H. Bakken (corresponding author), F. Kjosvik, A. Killangveit & K. Alfredsen

1 Norwegian University of Science and Technology, Department of Hydraulic and Environmental Engineering, NO-7491 Trondheim, Norway. Corresponding author: toy.h.bakken@ntnu.no. Tel: +47 99156944

1 SINTEF Energy Research, NO-7465 Trondheim, Norway

1 INTRODUCTION

IPCC (2011) presented an extensive review of the potential for renewable energy sources to replace fossil-based fuels and also benchmarked the different renewable technologies. One of the benchmark criteria were the water consumption of electricity production or the water footprint. IPCC (2011) revealed potentially very high water consumption rates from hydropower compared to the other renewables, up to a maximum of 209 m³/MWh due to evaporative losses from the reservoir surfaces, but it was noted that only a very few studies were available and a number of methodological problems were identified. More recent publications (e.g., Mekonnen and Hoekstra 2012, Danake et al. 2015, Bakken et al. 2015) present new estimates on water consumption from hydropower projects far beyond those earlier published by IPCC (2011), but do not provide a more consistent picture of the true water consumption of hydropower. In the upper range, Mekonnen and Hoekstra (2012) find that the sum of evaporated water (water footprint) of a sample of 35 evaluated hydropower reservoirs is similar to 10% of the global blue water footprint from crop production and therefore argue that production of hydropower is a large-scale water consumer. Similarly, Gerten, Leenheer et al. (2009) has calculated extremely high values for water consumption from hydropower production. Studies within this field of science have, however, also been criticized (e.g., Danake et al. 2015; Chenoweth et al. 2014, Bakken et al. 2015) due to its weak methodological basis. Given the fact that there is a growing interest in assessing the water footprint of various products, with reference to for instance the on-going development an ISO Water Footprint standard (ISO 14046 2014), we find it reasonable to present our views on the relevance of assessing the water footprint of reservoirs with hydropower production. Before we continue the discussion we would recall the purpose of reservoirs that are to store water from the wet to the dry season in order to supply water of sufficient quantities to the needs of the growing regional population and industry.
Thank you for listening!

Acknowledgment:
Jørgen Rugelbak, Fredrikke Kjosavik, Ånund Killingtveit & Knut Alfredsen (Norwegian University of Science and Technology)
Rune Engesæter (NNCOLD, NVE)