Evaporation from reservoirs and Hydropower Water Footprint Estimation

M. Marence, A. Mynet, T. Demeke

Water Footprint Concept

The water footprint of a product (a commodity, good or service) is the total volume of freshwater used to produce the product, summed over the various steps of the production chain. The water footprint of a product refers not only to the total volume of water used; it also refers to where and when the water is used.

(Source: Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011) The water footprint assessment manual: Setting the global standard, Earthscan, London, UK.)

Green water footprint:

- volume of rainwater evaporated or incorporated into product.

Blue water footprint:

- volume of surface or groundwater evaporated, incorporated into product or returned to other catchment or the sea.

Grey water footprint:

- volume of polluted water.

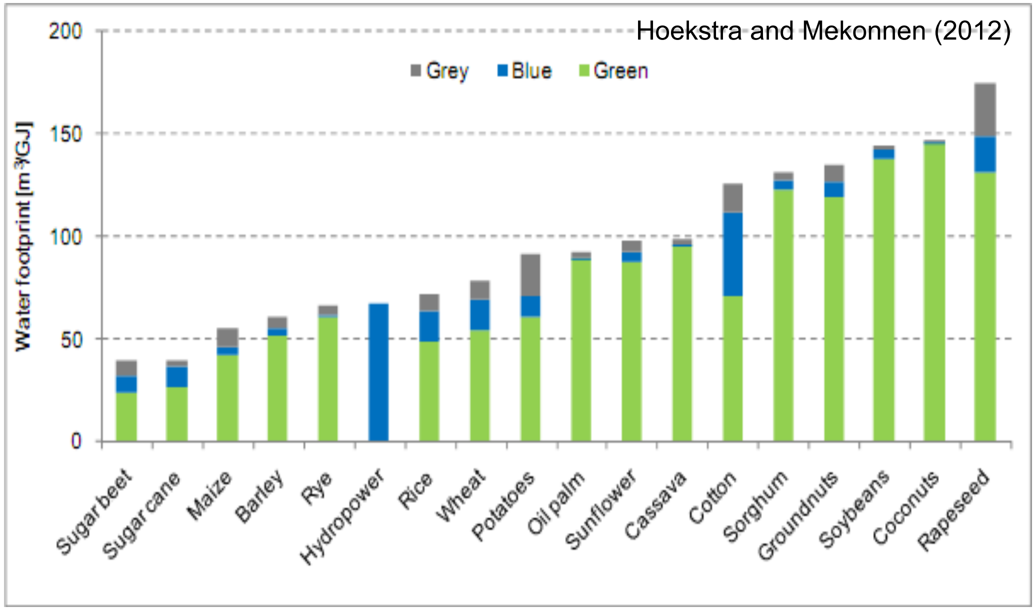
[Hoekstra & Chapagain, 2008]

Existing Studies

- Gleick (1993) – connected evaporation with hydropower plants (20 m³/GJ)
- Hoekstra (2008) – 22.3 m³/GJ
- Hoekstra and Mekonen (2012) – 68.0 m³/GJ
- Hearth (2011) – New Zealand - < 20 m³/GJ

Comparison with other electrical energy sources [m³/GJ] _Hoekstra (2008)

– Wind energy	0.00
– Natural gas	0.04
– Nuclear energy	0.09
– Coal	0.16
– Solar thermal	0.30
– Hydropower	22.30
– Biomass (NL)	24.16
– Biomass(BR)	61.20
– Biomass (Zimbabwe)	142.62



Where the Water can be Lost (Consumed) by Hydropower?

- Evaporation (blue footprint)
- Seepage out of reservoir (up to 5% of reservoir volume) - is it lost or just change?
- By diversion power systems in same watershed (local removal - not footprint)
- Diversion of water in other watershed (based on definition a footprint)
- No water pollution (no grey footprint)

- Calculation of water footprint;

$$WFP = \frac{EW}{GE} \quad \left[\mathrm{m^3/MW}\right]$$

Evaporation

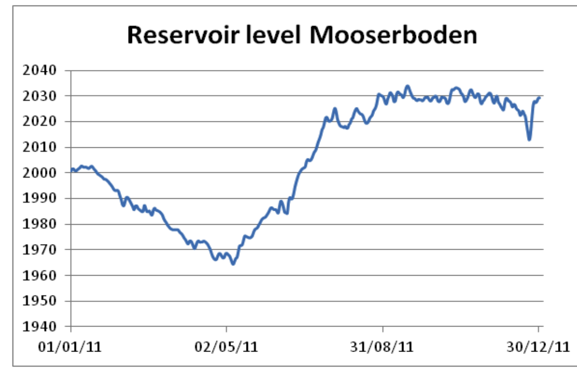
- Dependent on reservoir area, depth, temperature and **climate**
- Three methods for evaporation definition:
  - total evaporation of reservoir
  - net evaporation (evaporation – transpiration before)
  - subtracting rainfall
- Annual evaporation
  - 500-700 mm/year (continental climate, Europe)
  - < 3000 mm/year (arid areas, Aswan)
  - Hoekstra (2012) – average in their study 2320 mm/year

Evaporation

Direct measuring

Penman-Monteith method (function of radiation, vapour pressure, wind...)

$$E = \frac{1}{\lambda}\left[\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n - G) + \left(\frac{\gamma}{\Delta+\gamma}\right)f(u)(e_s - e_a)\right]$$

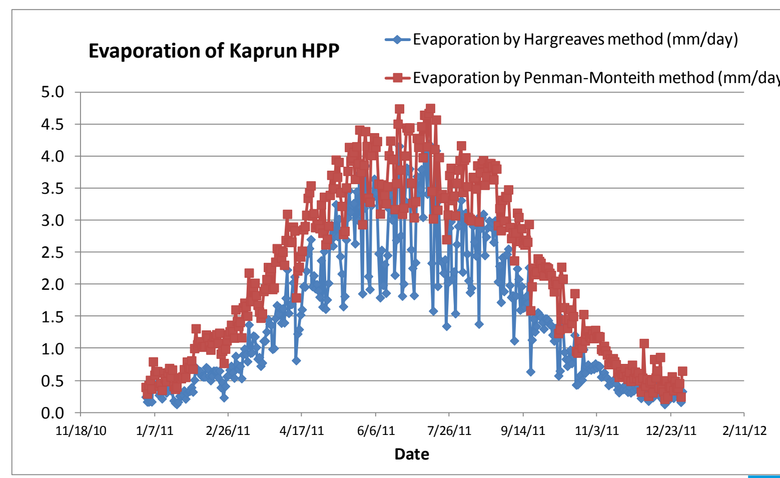


Hargreaves method (temperature, radiation)

$$ET = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$$

Annual reservoir evaporation volume

$$EW = \sum_{1}^{365} E * A_r(h)$$



HPP Footprint

Reservoir	Country	Reservoir area (ha)	Installed capacity (MW)	Evaporation (mm/year)	Water footprint (m^3/GJ)	Remark evaporation
Tekeze	Ethiopia	14,700	300	1,920	79.9	Measured
Finchaa-A-N	Ethiopia	29,330	128	1,650	208.4	Measured
Geba	Ethiopia	11,000	371	1,675	30.5	Measured
Arkun	Turkey	553	236	683	1.3	Measured
Soylmez	Turkey	4,534	36	548	32.9	Measured
Atatürk	Turkey	81,700	2,400	1,000	25.5	Measured
Kaban	Turkey	67,500	1,300	710	22.2	Measured
Gigel Gibe I	Ethiopia	6,300	184	1,786	36.9	Hargreaves
				2,122	43.8	Penman-Monteith
				1,837	38	Measured
Kaprun	Austria	329	353	545	0.8	Hargreaves
				802	1.1	Penman-Monteith
				600	0.8	Measured
Nam Ngum 2	Lao DR	12,200	615	1,009	15.3	Hargreaves
				1,551	23.5	Penman-Monteith
				1,600	24.2	Measured
Akosombo	Ghana	850,000	1,020	1,500	737.8	Measured
Aswan	Egypt	525,000	2,100	3,000	1,736	Measured max.

Influence of reservoir level oscillation:

- Kaprun, Austria – 30%
- Nam Ngum II, Lao DR – 21%

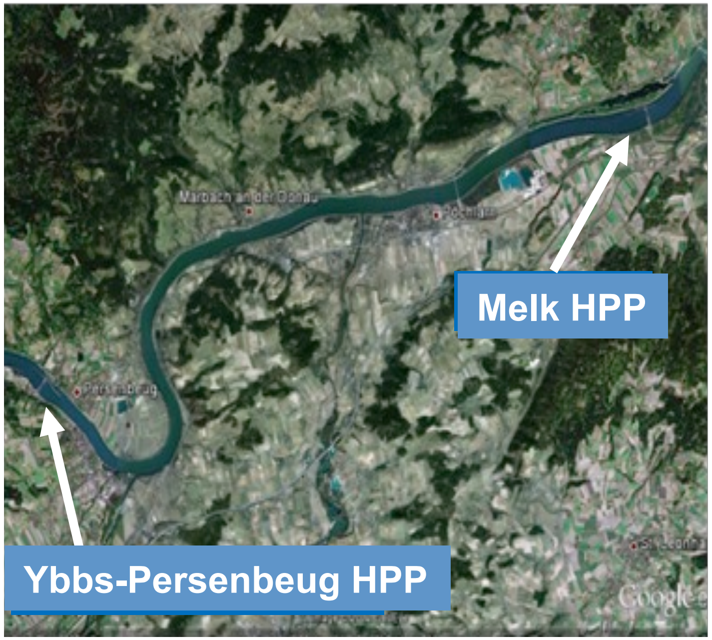
Factors Influencing Water Footprint

Evaporation:

- Reservoir area (additionally flooded area)
- Climate
- Reservoir level variation

Energy production:

- Head
  - reservoir plants mostly higher head
  - near the dam or diversion plant



- Discharge
  - reservoir volume (area and reservoir depth)
  - peak or base power plant

Hydropower Plants

Run-of-river plants:

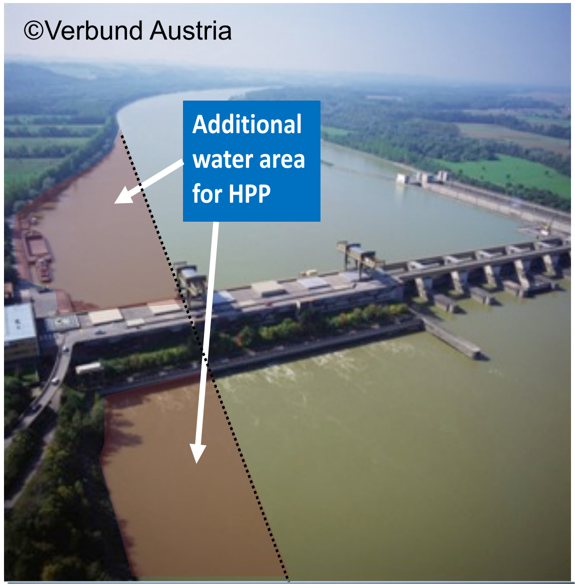
- no reservoir = no footprint

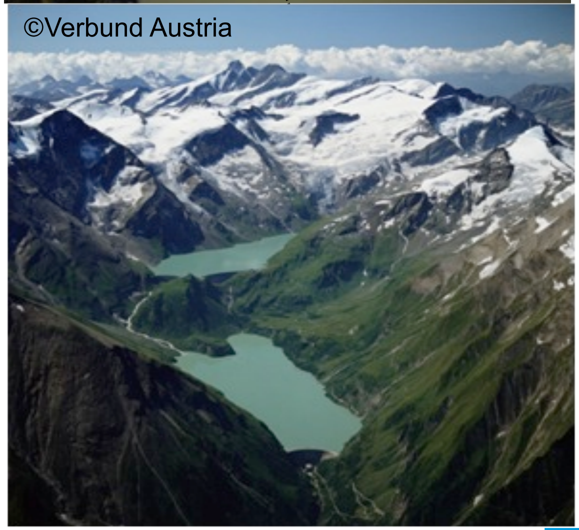
Storage plants:

- evaporation of reservoir
- dependent on actual reservoir area (reduction by 20-30%)
- flood regulation = reduction of flood evaporation
- system of reservoirs instead one large reservoir

Small hydropower plants

- no reservoir
- concept as run-of-river plants
- portion of flow



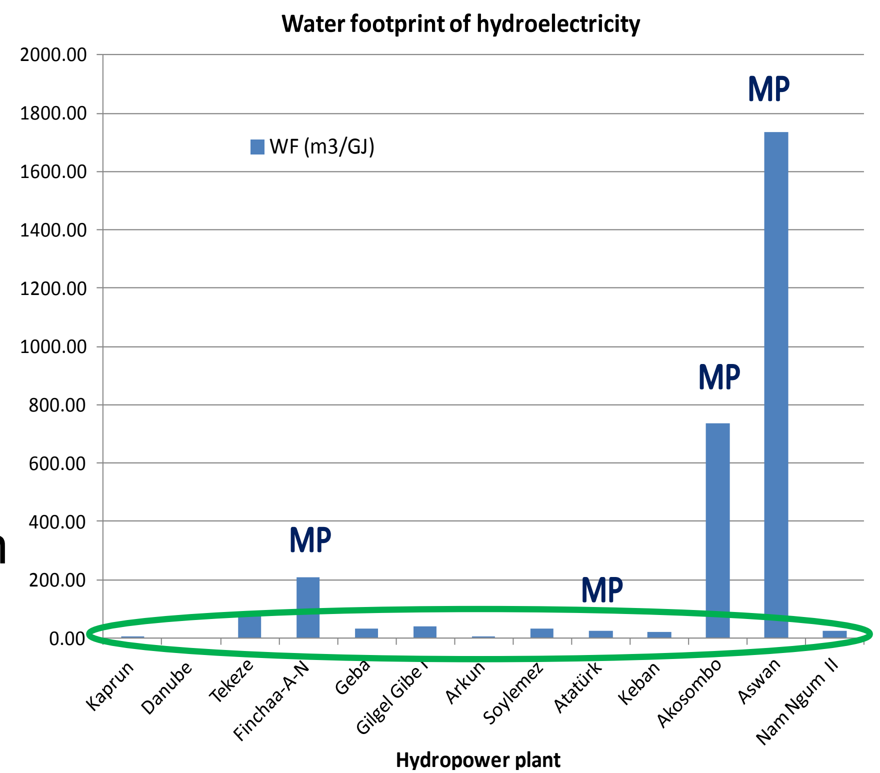


Multipurpose Reservoirs

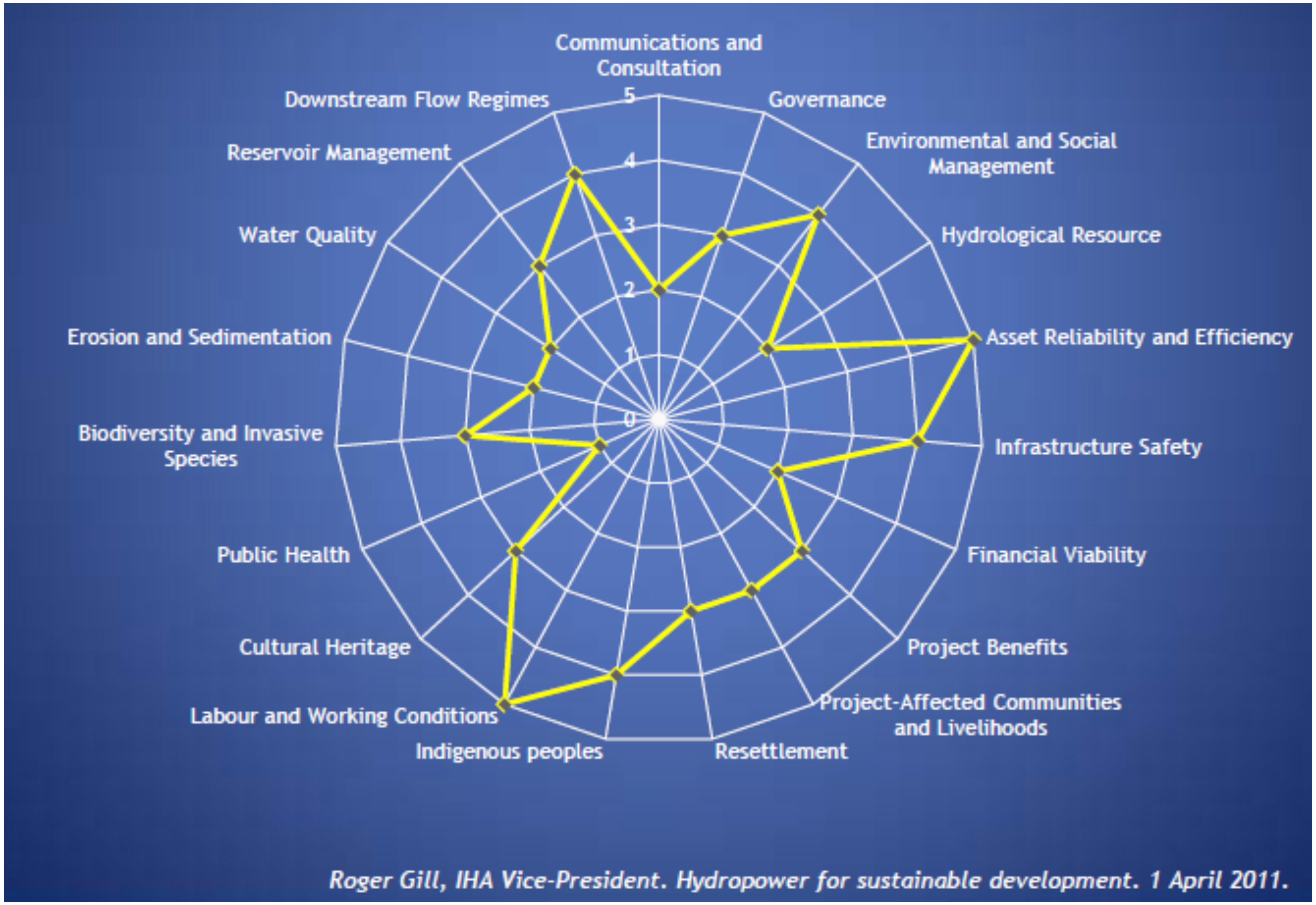
- Flood control
- Water supply (human and industrial)
- Recreational use and tourism
- Agriculture

How to calculate part of evaporation by multipurpose plants?

- deduct other uses
- as ratio of the real energy production compared with maximal possible production



Sustainable Hydropower



Water footprint as one of factors by
Hydropower Sustainability Assessment Protocol

Conclusions

- Water, lost by **evaporation,** usually lives the hydrologic basin and therefore it is a **real loss**, but evaporation changes the local microclimate and mostly acts positively in the system.
- Calculation of the water footprint of hydropower (consumption of the water) is complicated and must take into consideration the **multipurpose** use of reservoirs and water requirements of others.
- Evaporation in the reservoir area (transpiration) before impounding could be subtracted from the total evaporation.

- Water lost by seepage remains in basin and can become available again downstream
- Water transported in another watershed should be included in water footprint

- "**Objective hydropower footprint**", cleaned from other multipurpose factors and related only to hydropower production should be introduced
- Objective hydropower water footprint should be an additional ecological parameter for hydropower plant characterization, but not a value for hydropower degradation

Instead of use, hydropower (reservoir) should conserve water!

THANK YOU FOR YOUR ATTENTION

UNESCO-IHE Institute for Water Education
www.unesco-ihe.org