Water consumption from hydropower production: review of published estimates

Tor Haakon Bakken[1&2], Ånund Killingtveit[1],

Kolbjørn Engeland[2], Knut Alfredsen[1] & Atle Harby[2]

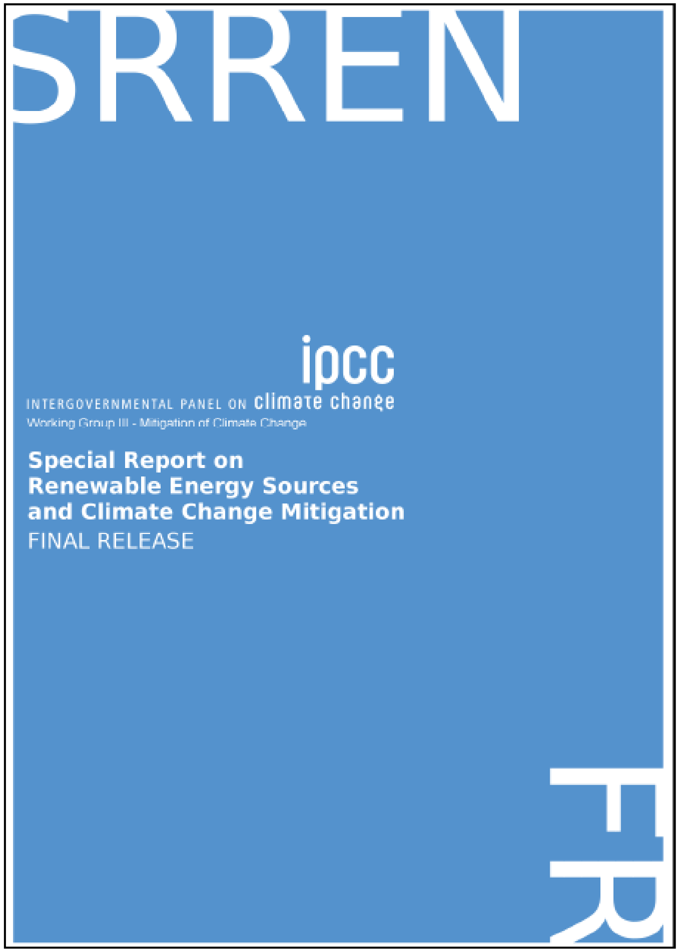
[1] Norwegian University of Science and Technology, Trondheim, Norway
tor.haakon.bakken@sintef.no

[2] SINTEF Energy Research, Trondheim, Norway

Structure of talk

1. Background
2. Review of published estimates
3. Critique of concept
4. Summed up

What raised the attention?

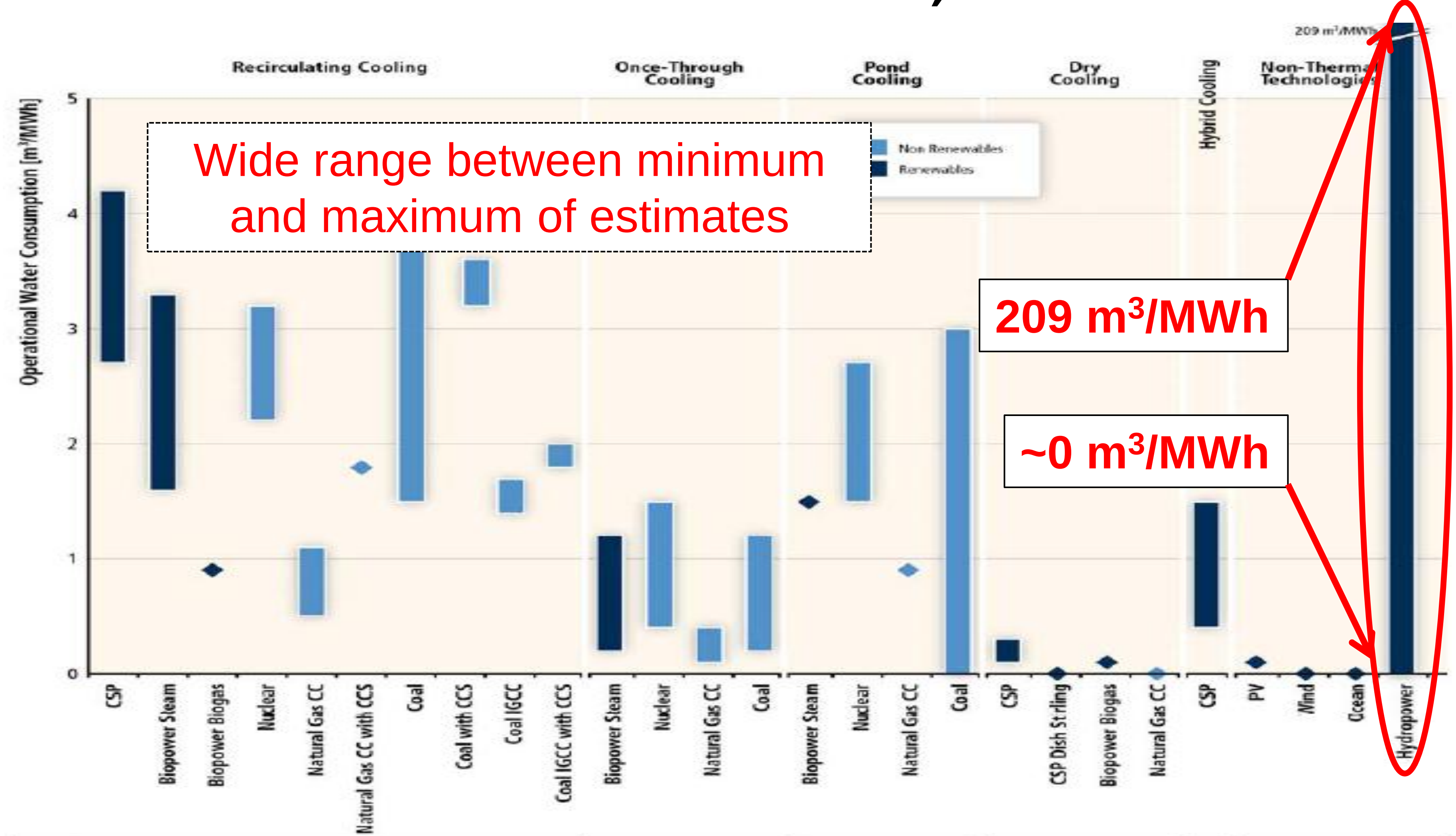


IPCC Special Report on Renewable Energy (2012):

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

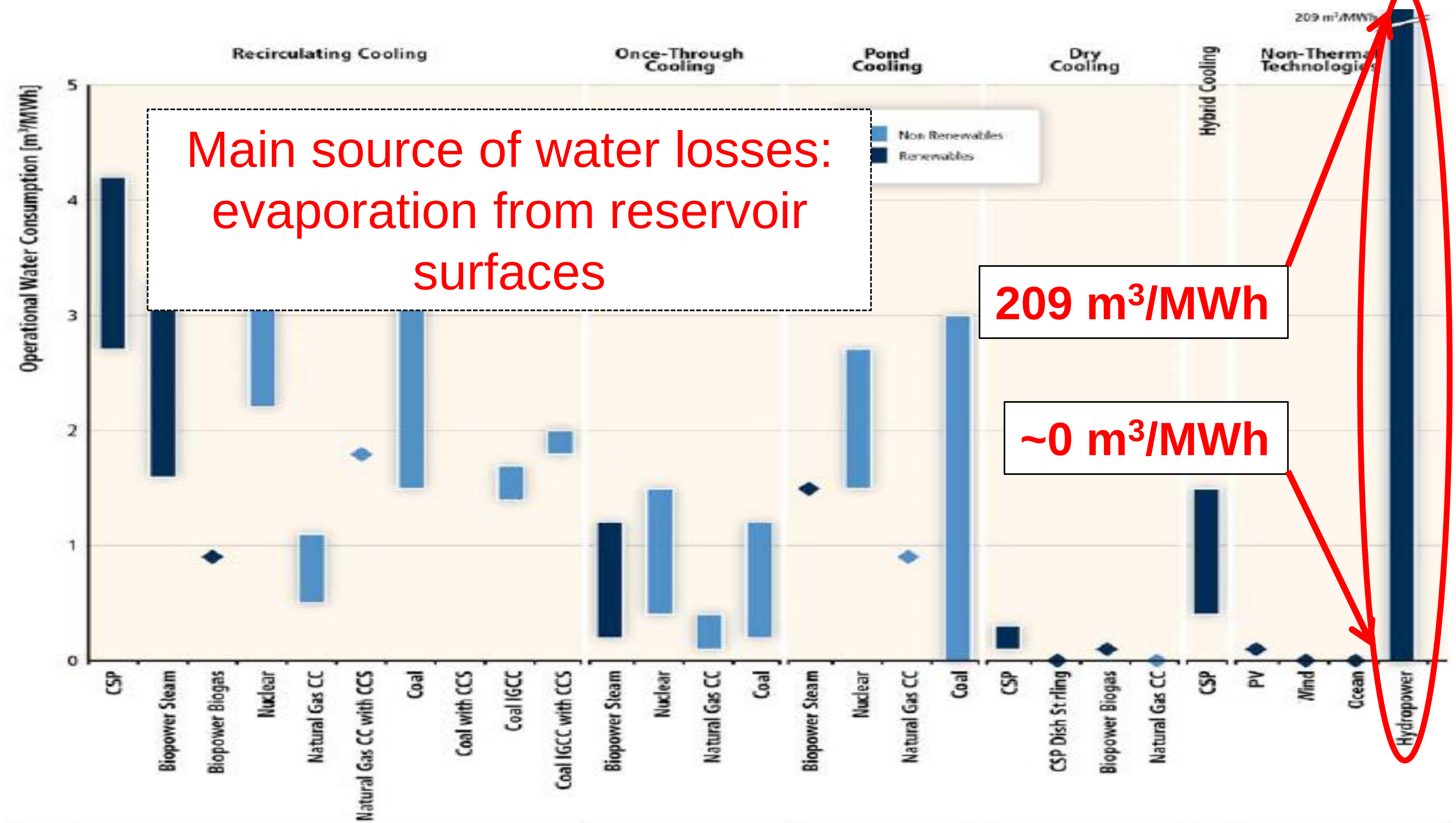
- The different technologies benchmarked with respect to various criteria, including ‘water needed to produced 1 MWh electricity (*water consumption*)’

Water consumption from energy generation: *Source: IPCC SRREN, 2012*



N:	18	4	1	5	4	1	16	2	7	3	1	3	3	9	1	1	1	7	11	2	1	2	4	2	2	1	4
Sources:	11	3	1	5	4	1	8	1	2	1	1	3	3	4	1	1	1	2	4	2	1	2	2	2	2	1	2

Water consumption from energy generation: *Source: IPCC SRREN, 2012*



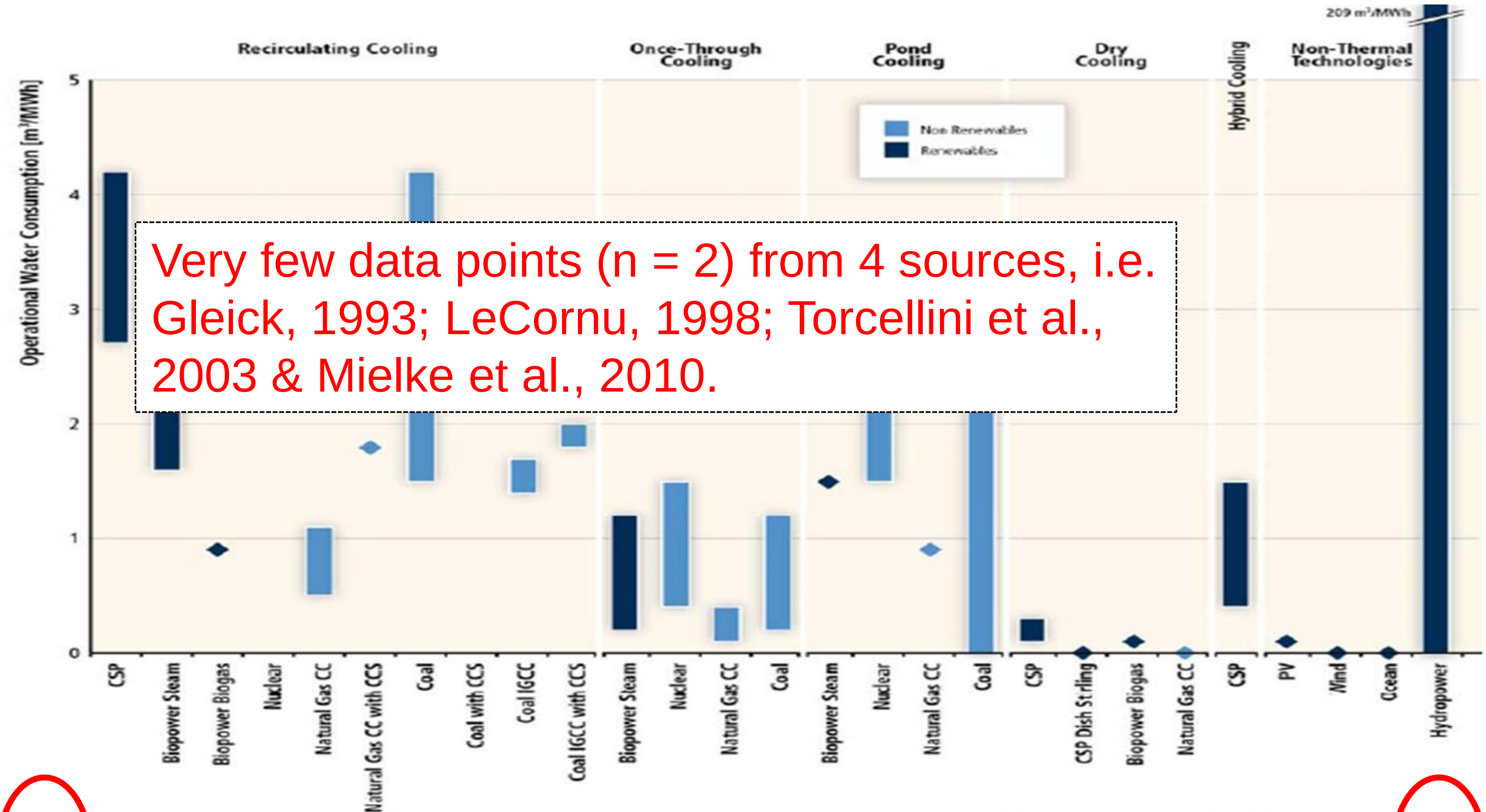
N:	18	4	1	5	4	1	16	2	7	3	1	3	3	9	1	1	1	7	11	2	1	2	4	2	2	1	4
Sources:	11	3	1	5	4	1	8	1	2	1	1	3	3	4	1	1	1	2	4	2	1	2	2	2	2	1	2

Main source of water losses: evaporation from reservoir surfaces

209 m³/MWh

~0 m³/MWh

Water consumption from energy generation: *Source: IPCC SRREN, 2012*



N:	18	4	1	5	4	1	16	2	7	3	1	3	3	9	1	1	1	7	11	2	1	2	4	2	2	1	4
Sources:	11	3	1	5	4	1	8	1	2	1	1	3	3	4	1	1	1	2	4	2	1	2	2	2	2	1	2

Very few data points (n = 2) from 4 sources, i.e. Gleick, 1993; LeCornu, 1998; Torcellini et al., 2003 & Mielke et al., 2010.

IPCC SRREN (2012) 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.*

Why this concern in the HP sector?

- The picture on hydropower is very inconsistent
- Very limited data/investigations and immature concept
- A fear that these numbers can be taken as 'typical water footprint of hydropower'

- Potentially a large reputational and business risk
- Might disqualify hydropower based on an unfair methodological basis
- The water footprint methodology seems to gain an increasing foothold

Main source of water losses: evaporation from reservoir surfaces

Results from our review documented in:

1 Proceedings of H09, IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, July 2013 (IAHS Publ. 362, 2013).

2 HESS Discussion (open until August 19^{th}, 2013):

http://www.hydrol-earth-syst-sci-discuss.net/10/8071/2013/

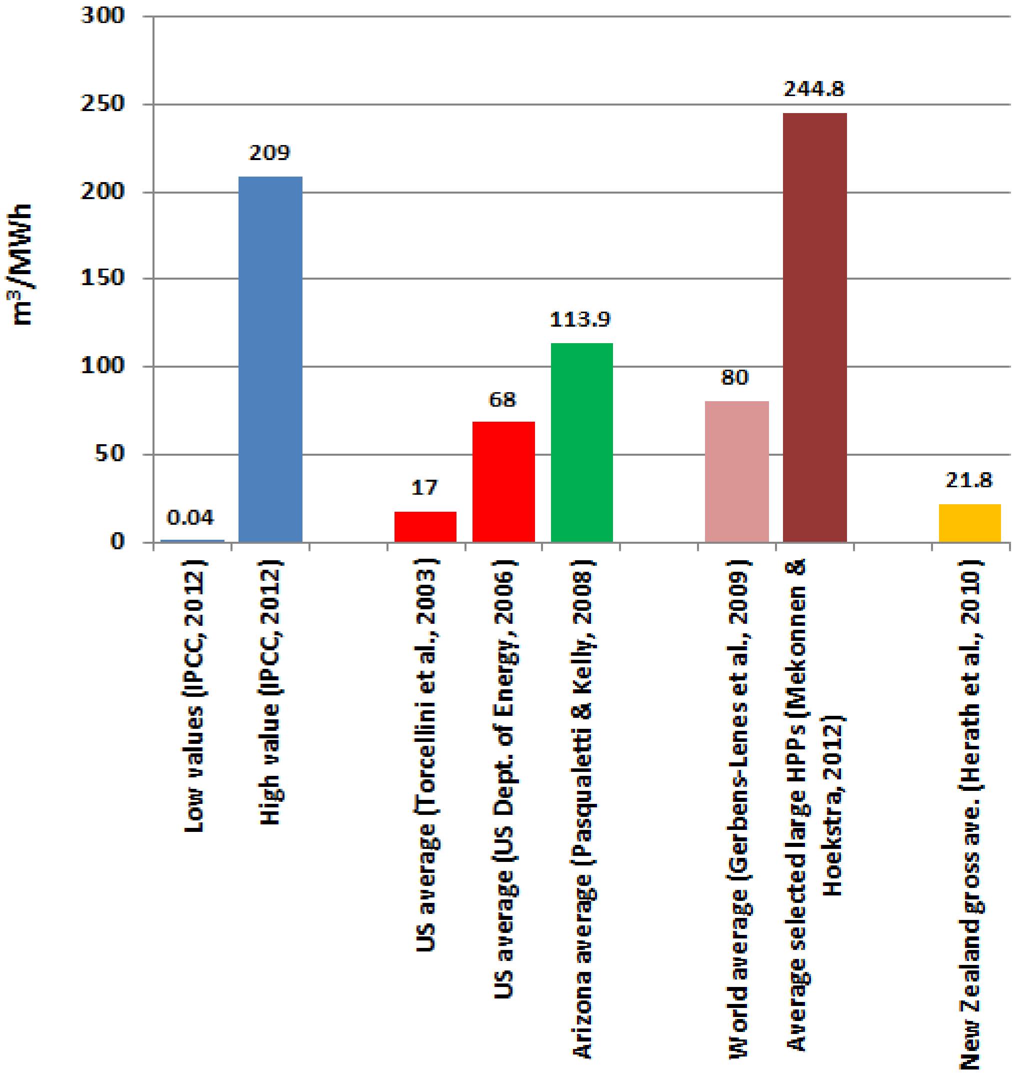
Basis for calculations

1. $$Gross\ water\ consumption = \frac{Evaporation\ reservoir}{Annual\ power\ production}$$

2. $$Net\ water\ consumption = \frac{Evaporation\ reservoir - Evaporation\ before\ inundation}{Annual\ power\ production}$$

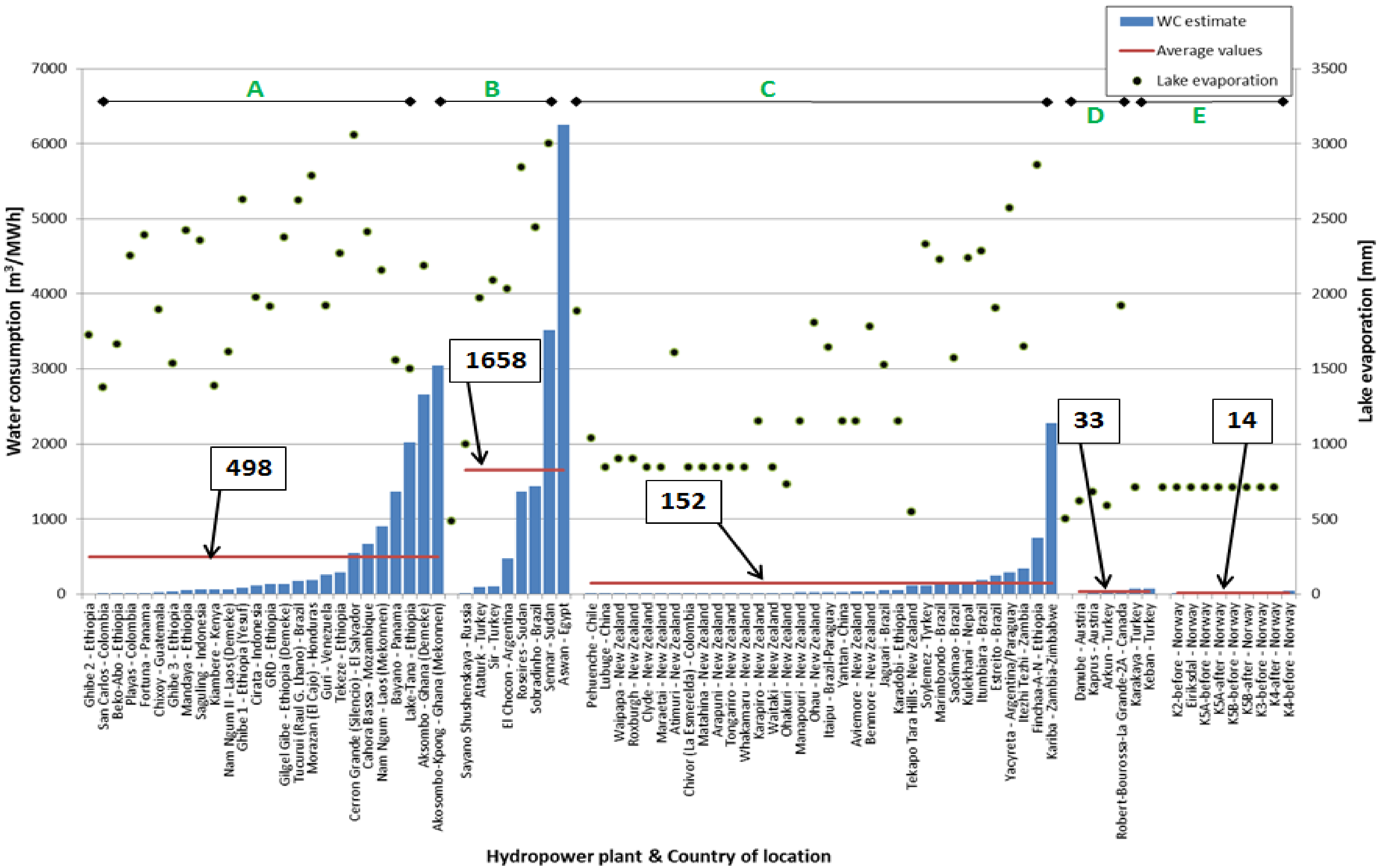
3. $$Water\ balance = \frac{Evaporation\ reservoir - Direct\ rainfall\ reservoir}{Annual\ power\ production}$$

Selected benchmarks published – Gross values

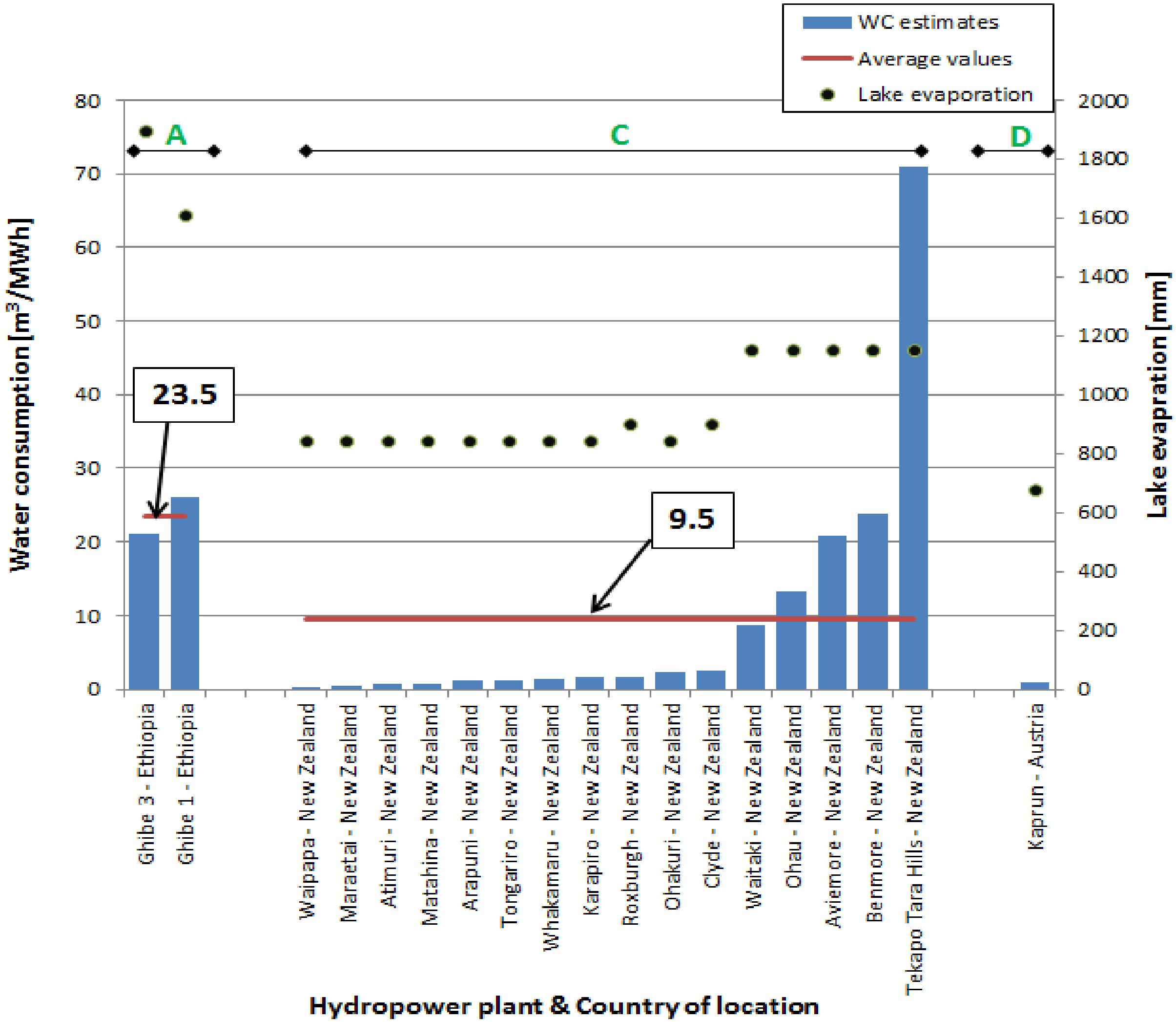


- 'IPCC-values'
- US averages, based on 2 different datasets
- World average based on 2 different datasets
- 2 regional averages (Arizona and NZ)

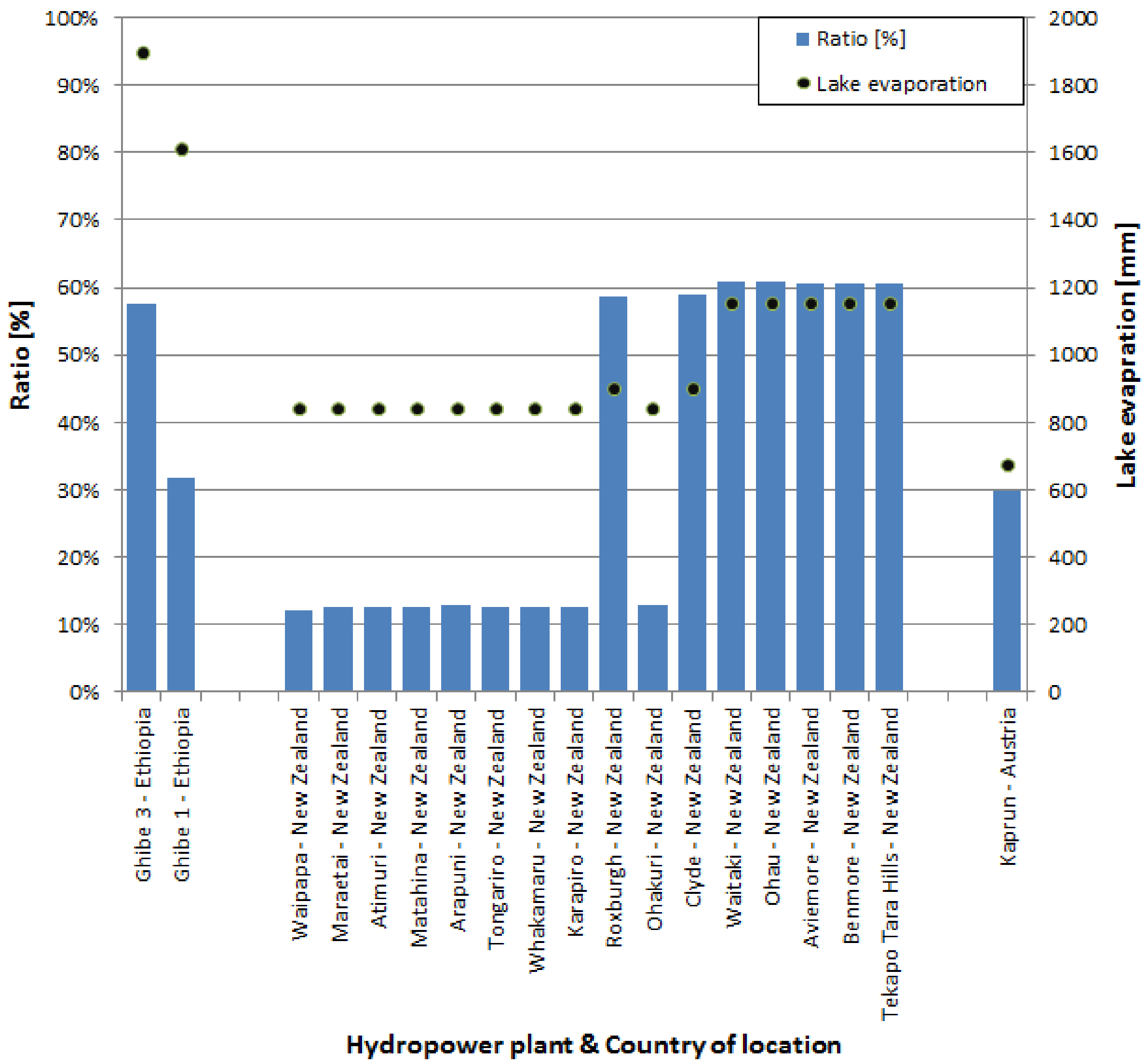
Single-plant studies – Gross values



Single-plant studies – <u>Net</u> values



Ratio Net/Gross water consumption



Findings from our review of published values

- The presented estimates are based on different methodological approach. The dominating approach is the gross evaporation divided on production.
- Some of the newly published estimates are far beyond the earlier published maximum values by IPCC (2012).
- Only three studies report both gross and net evaporation. In these cases the net evaporation was 10-60 % of gross evaporation (water consumption).
- One study give negative water footprint (according to the 'water balance-method')
- Some studies are single-plant studies, while others have a very large geographical extent, 'smoothening out' large variations in water consumption values.

Findings from our review of published values

- Some of the high estimates are from reservoir with irrigation as the primary purpose and limited hydropower production, and/or large (natural) lakes with limited withdrawal of water for HP production.
- One study attempts to assign water losses according to the water value of the various uses (in multi-purpose reservoirs).
- Water consumption estimates are very sensitive to evaporation estimates, and the qualities of these estimates are uncertain.
- The studies/publications range in quality.

Findings from our review on the concept of assessment

- "No way" around the fact that HP has a large water consumption in some regions, given the current approach (gross evaporation) of calculating water consumption/footprint.

- But, are high water consumption rates problematic?

- No solution on how to handle "impacts" on the water resources, brief sketches of concepts proposed by e.g. Ridoutt & Pfister, 2010; Pfister et al., 2011; Hoekstra et al., 2011; Zeng et al., 2012.

Critique: Methodological problems (1/2)

1. Values are given as gross evaporation from the reservoir area. For dams constructed on desert land, the net evaporation will be equal to the gross values, but in most cases evaporation will be less, especially for dams in wetland areas and areas with vegetation where the net increase may be very limited.

2. Water stored in 'hydropower' reservoirs is often used for multiple purposes; thus the evaporation losses should not all be assigned to the hydropower production.

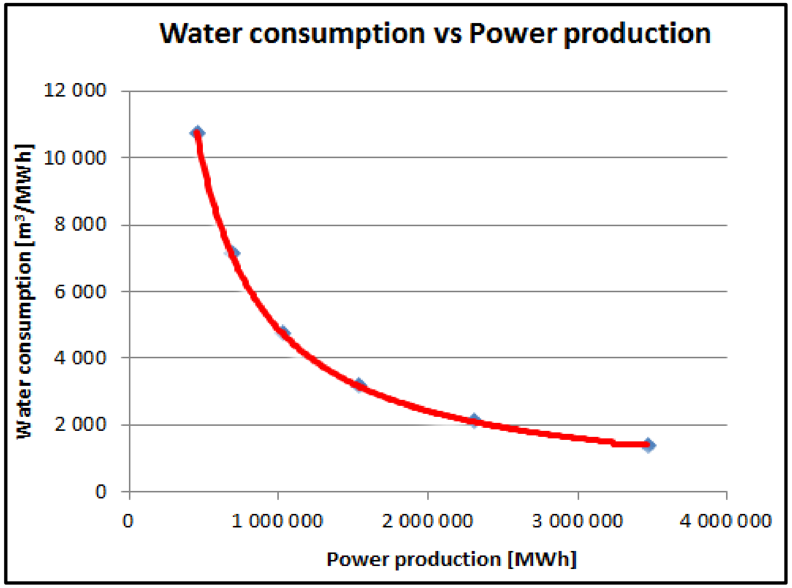
3. Impacts from the water consumption/footprint is ‘ignored’.

4. Construction of dams is a very common way to improve the availability of/access to water.

Critique: Methodological problems (2/2)

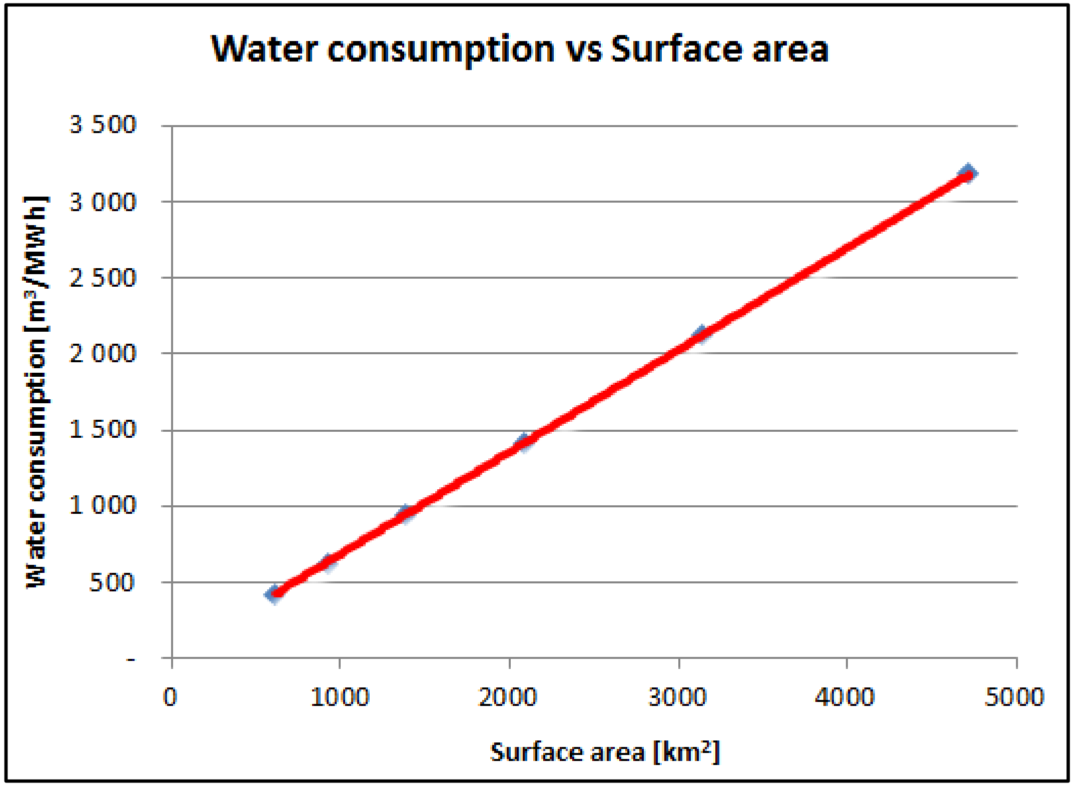
5. How to set the right system boundaries in space and time?

   - One reservoir might serve several hydropower plants
   - The production might vary a lot during the year and from year to year – what is the temporal resolution and span?

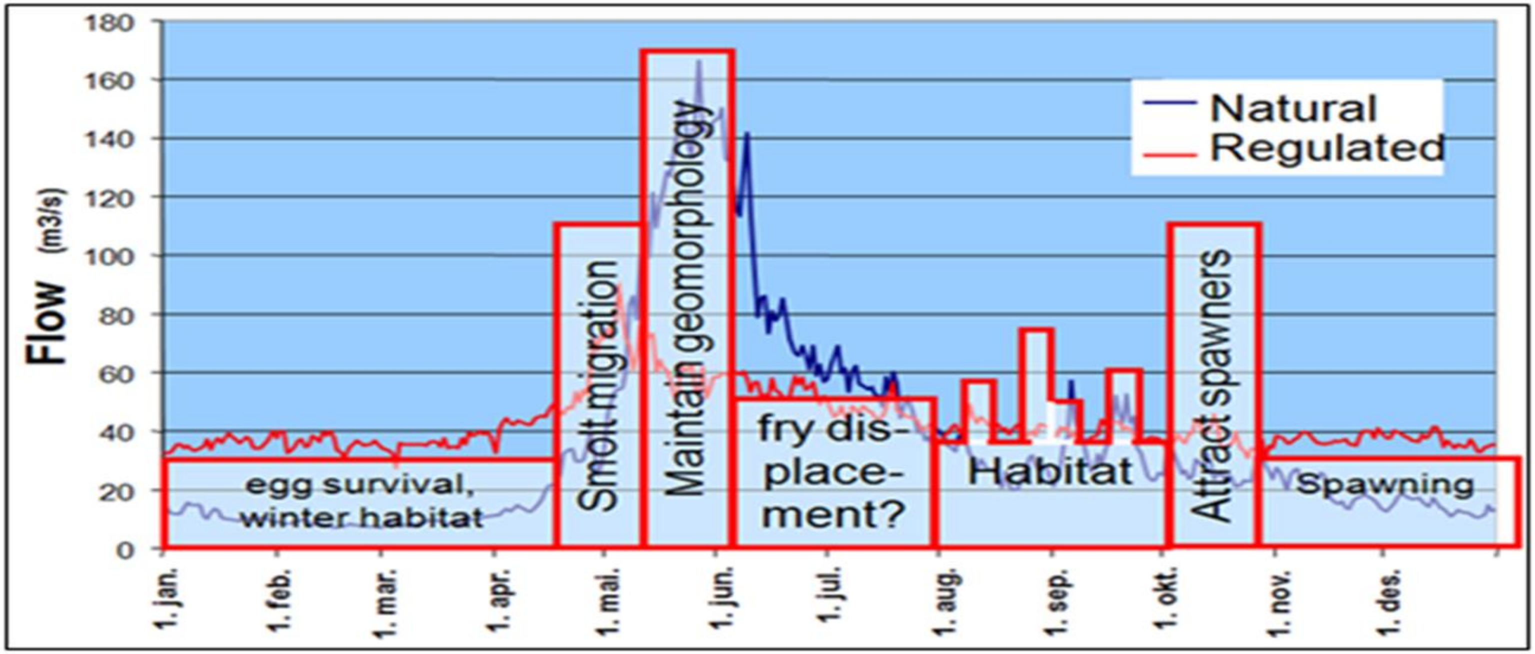


Critique: Methodological problems (2/2)

7. What about the use of existing lakes as reservoirs – should all evaporation losses be assigned to the hydropower production?

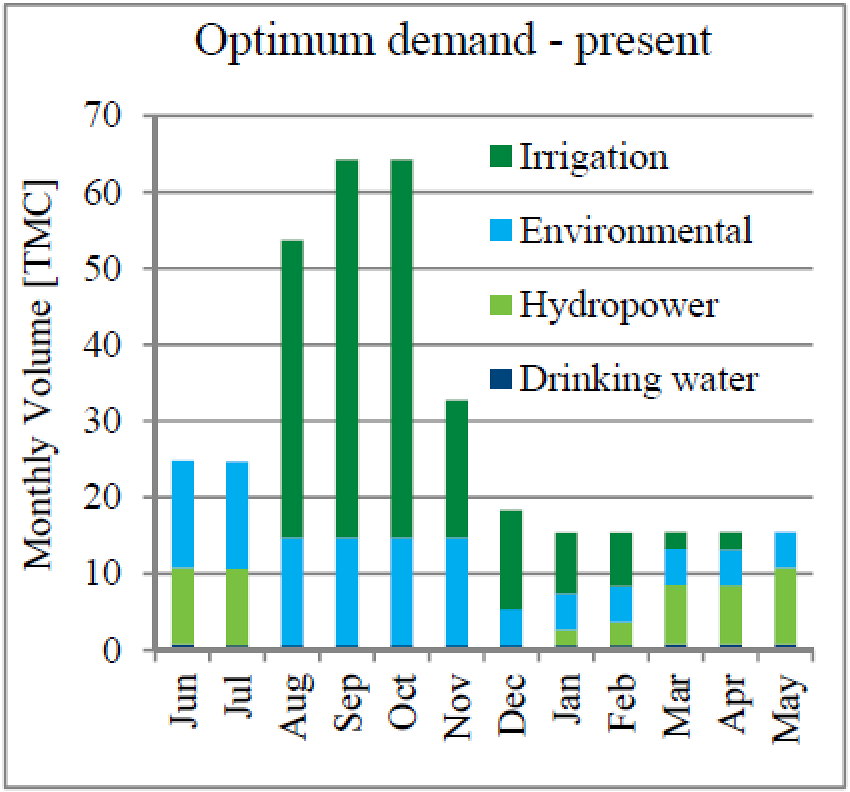


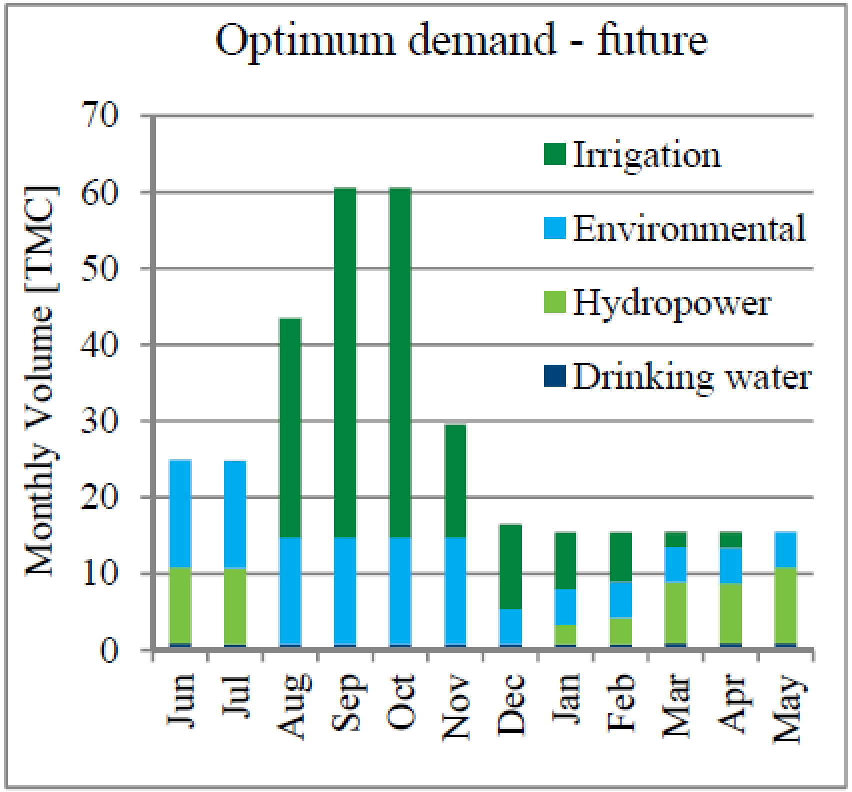
How to describe the availability of water?



Can the concept be transferred into finding the optimum water allocation in a setting of competing sectors interests?

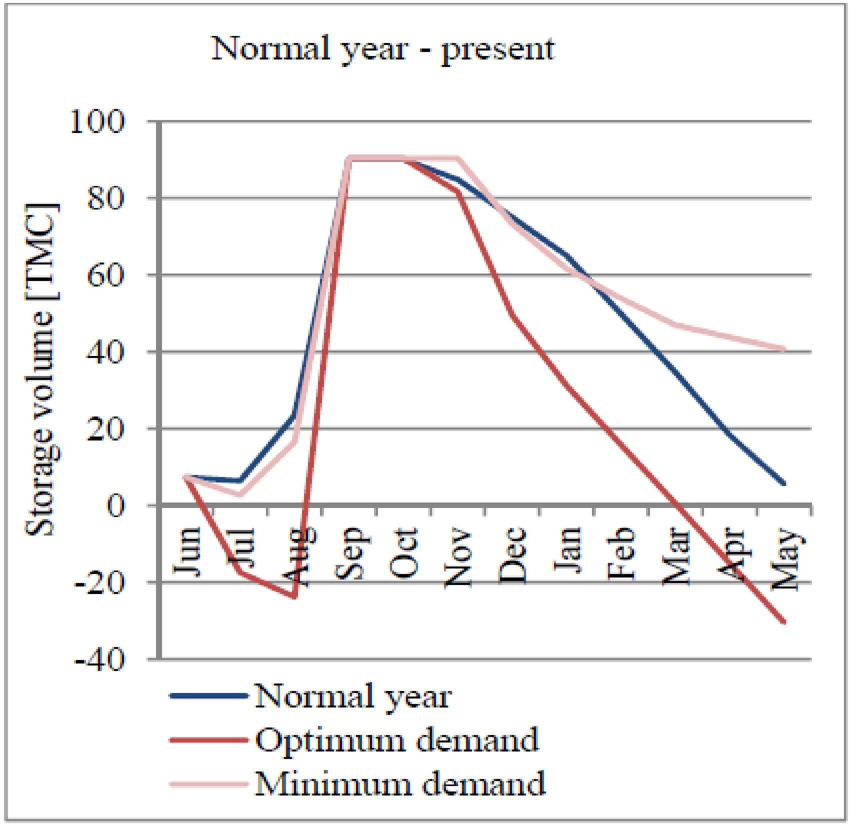
Application of the Building Block Methodology (BBM) in India

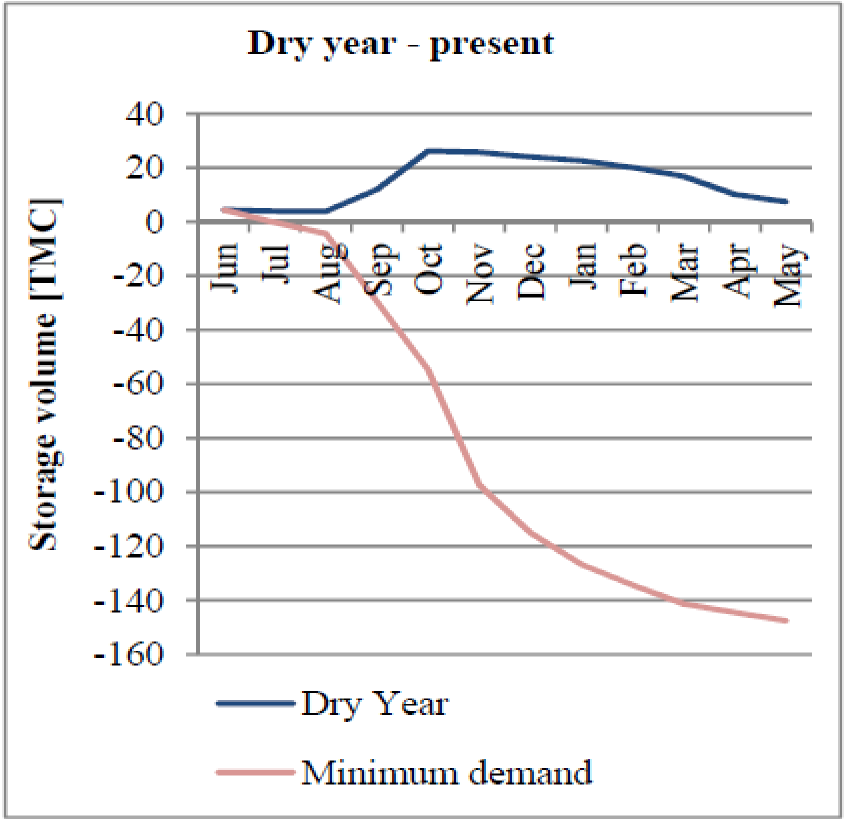




Water needs today and in 10 years time (when introduced water saving measures)

Application of the Building Block Methodology (BBM) in India



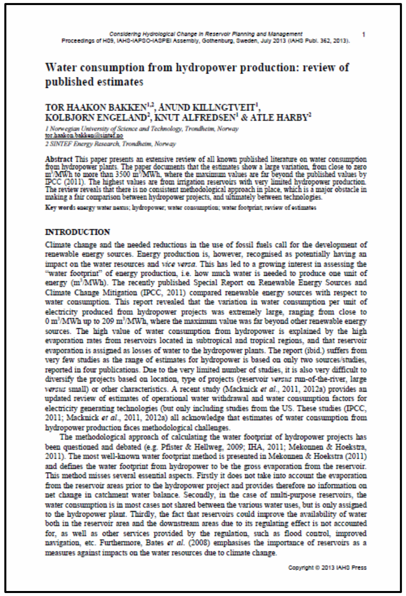


Storage volumes in the case of ‘normal’ hydrological year and a dry year

Summed up

- The recently published values vary a lot and new studies are even far beyond values published by IPCC (2012).
- The concept of assessment appears to be over-simplified.
- It appears as a contradiction to assign water losses to reservoirs as their main purpose is to increase the water availability for various purposes.
- The impact of the (high) water consumption/footprint values should be assessed, in a local or regional context.
- But, water losses occur and should be taken into consideration in the planning and operation of reservoirs.
- Improved quantitative descriptions of reservoirs influence on water availability needed

Documentation



Considering Hydrological Change in Reservoir Planning and Management
Proceedings of H09, IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, July 2013 (IAHS Publ. 362, 2013).

Water consumption from hydropower production: review of published estimates

TOR HAAKON BAKKEN[1,2], ÅNUND KILLINGTVEIT[1], KOLBJØRN ENGELAND[2], KNUT ALFREDSEN[1] & ATLE HARBY[2]

INTRODUCTION

Bakken, T.H., Killingtveit, Å., Engeland, K., Alfredsen, K., & Harby, A. (2013) Water consumption from hydropower production: review of published estimates. IAHS-AISH publication. volum 362.

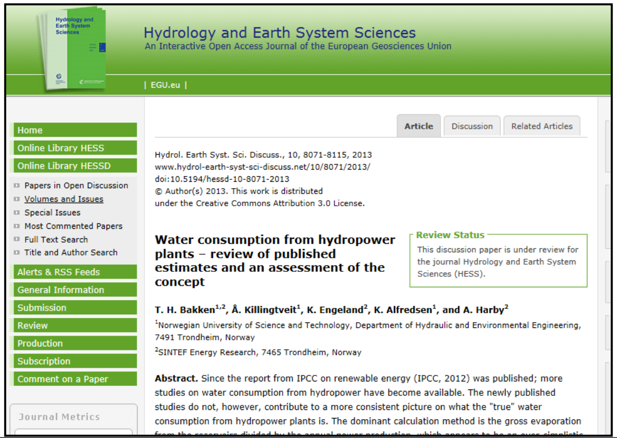
Journal of Sustainable Development; Vol. 6, No. 8; 2013
ISSN 1913-9063 E-ISSN 1913-9071
Published by Canadian Center of Science and Education

Water Allocation With Use of the Building Block Methodology (BBM) in the Godavari Basin, India

Abstract

1. Introduction

Bakken, T.H., Skarbøvik, E., Gosain, A.K., Palanisami, K.; Sauterleute, J.,Egeland, H., Kakumanu, K.R., Nagothu, S., Harby, A., Tirupataiah, K., & Stålnacke, P. (2013) Water Allocation With Use of the Building Block Methodology (BBM) in the Godavari Basin, India. Journal of Sustainable Development. volum 6 (8).



Hydrology and Earth System Sciences
An Interactive Open Access Journal of the European Geosciences Union

Hydrol. Earth Syst. Sci. Discuss., 10, 8071-8115, 2013
www.hydrol-earth-syst-sci-discuss.net/10/8071/2013/
doi:10.5194/hessd-10-8071-2013

Water consumption from hydropower plants – review of published estimates and an assessment of the concept

T. H. Bakken[1,2], Å. Killingtveit[1], K. Engeland[2], K. Alfredsen[1], and A. Harby[2]

Bakken, T.H., Killingtveit, Å., Engeland, K., Alfredsen, K., & Harby, A. (2013). Water consumption from hydropower plants – review of published estimates and an assessment of the concept. Hydrology and Earth System Sciences. volum 17.

Documentation

Master: Lake Turkana

NTNU – Trondheim
Norwegian University of Science and Technology

Impacts of Cascade Hydropower Plants on the flow of the River System and Water level in Lake Turkana in Omo-Ghibe Catchment, Ethiopia

Mamuye Busier Yesuf

Hydropower Development
Submission date: June 2012
Supervisor: Ånund Killingtveit, IVM

Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering

Master: Blue Nile

NTNU – Trondheim
Norwegian University of Science and Technology

The effect of Ethiopian hydropower reservoirs on the Blue Nile River flow regime

Muez Araya Tefferi

Hydropower Development
Submission date: June 2012
Supervisor: Ånund Killingtveit, IVM

Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering

Master: Water indices

Technische Universität Braunschweig

LWI Leichtweiß-Institut

NTNU – Trondheim
Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering IVM

Academic paper
submitted to attain the degree of

"Master of Science"

in the degree course Environmental Engineering

at the
Department of Hydraulic Engineering

of

Prof. Dr.-Ing. habil. Andreas Dittrich

Evaluation of methods measuring the water consumption of hydropower

Handed in by:
Sören Weichert
Matr.-Nr.: 3019020

Assistant Professor:
Knut Alfredsen
Professor, IVM, NTNU

Supervisor:
Tor Haakon Bakken
PhD Candidate, IVM, NTNU

Braunschweig, 19th November 2013

Master: Tydalen

Technische Universität Dresden

Estimation of evaporation from a Penman-Monteith model, parameterized from Eddy-Covariance measurements

Phillip Thumser

zum
Erlangen des akademischen Grades

DIPLOMINGENIEUR
(Dipl.-Ing.)

Betreuer: Bruno Giordano

‘The meat and the flesh’

The role of water losses due to evaporation in the planning and operation of reservoirs

River basin management

Statistical analysis

Climate change

Reservoir location and design

Water, energy and climate nexus

IPCC

Euphrates and Tigris

Ethiopia

Turkey

Multi-purpose reservoirs

Evaporation

Scientific openness and freedom

Water losses

Policy development

Water allocation

Water consumption

Resources optimization

Water planning

Operational management

Nile

Kargi

Fundamental research

Gross versus net

Explorative

Water availability

Modeling

Conjunctive use

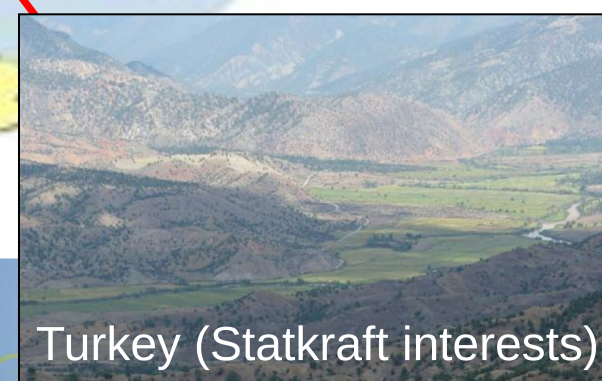
Water saving

Evapotranspiration

Possible Case studies

India ?????

Africa/ Ethiopia


Turkey (Statkraft interests)