Water consumption from hydropower production: review of published estimates

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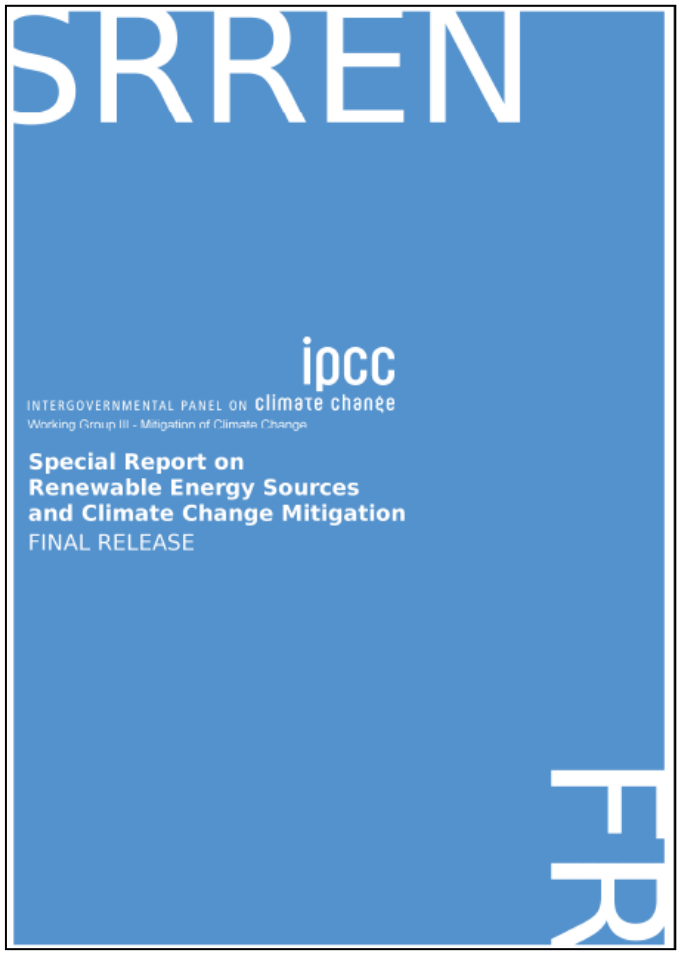
Structure of talk

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

What raised the attention?

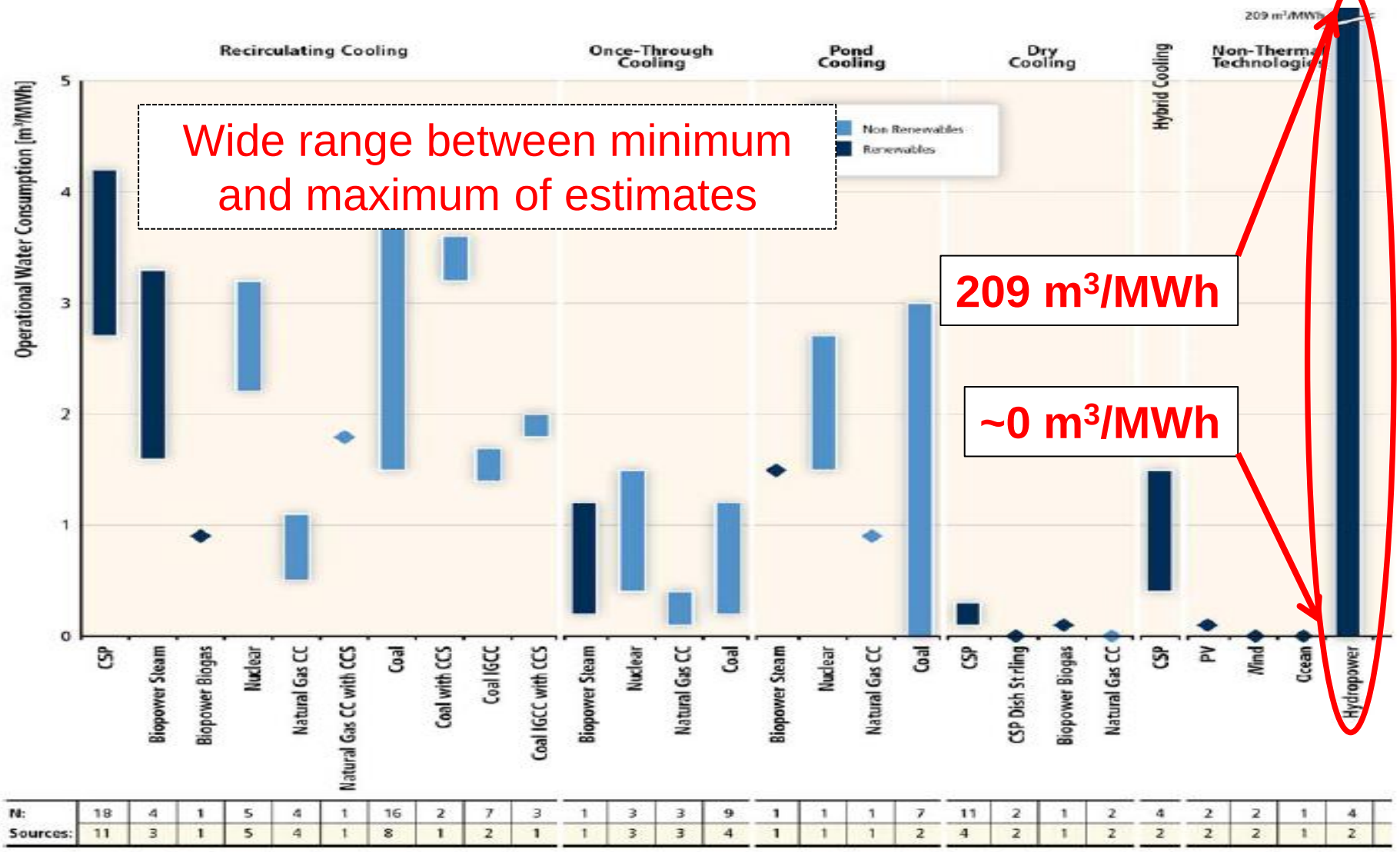


IPCC Special Report on Renewable Energy (2011):

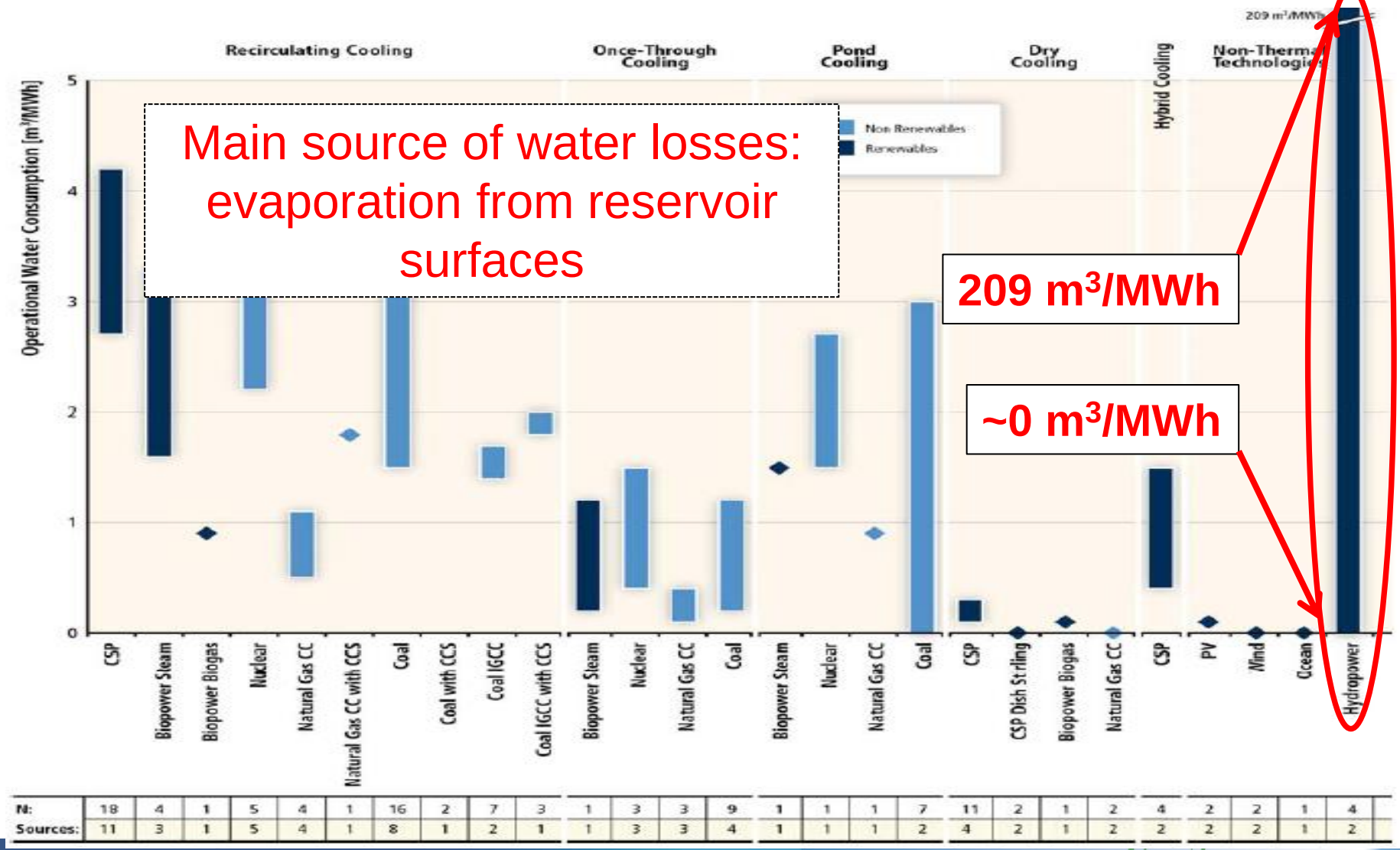
- What is the potential for renewable sources to replace fossil-based fuels?

- 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*



Water consumption from energy generation: *Source: IPCC SRREN, 2011*



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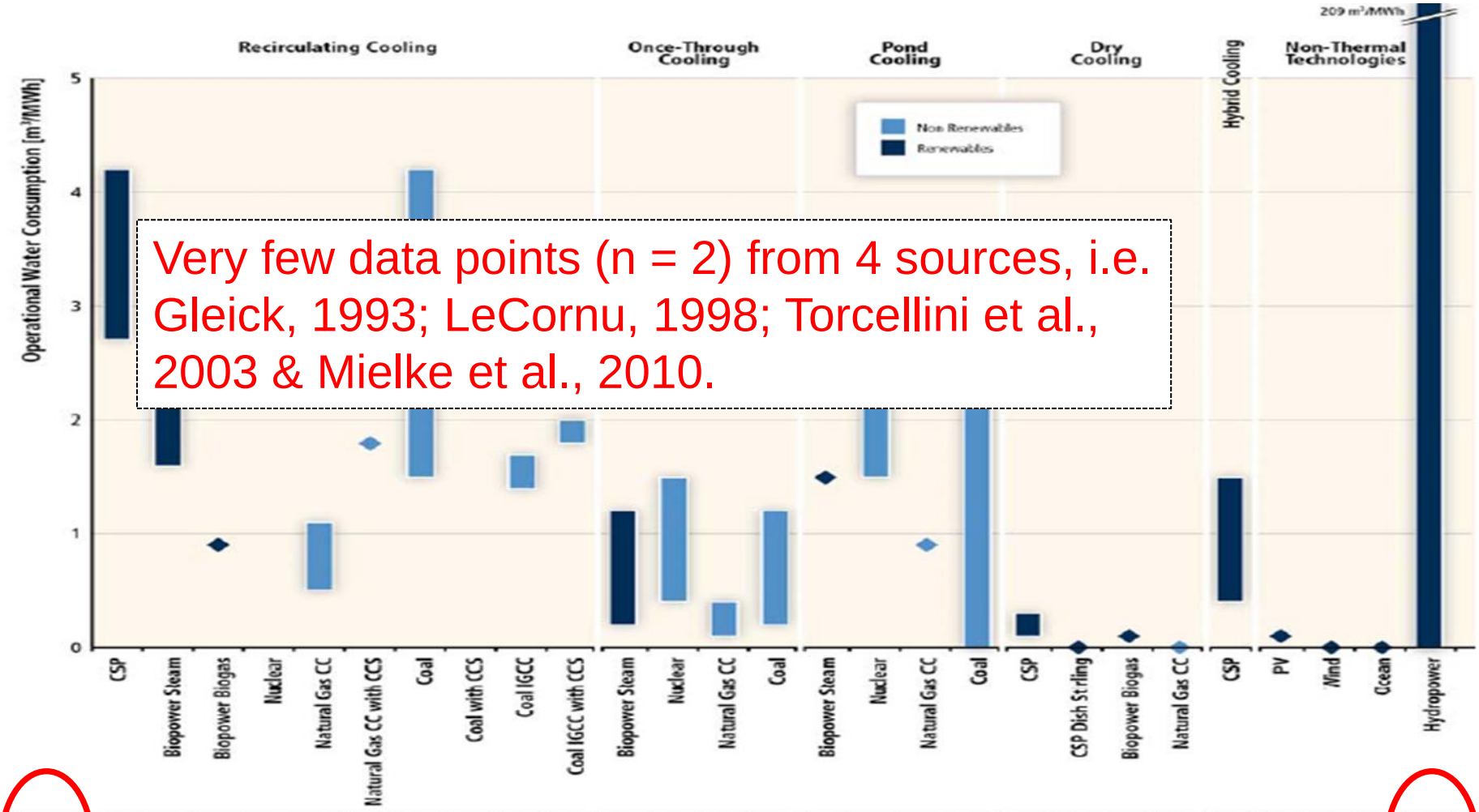


Very few data points (n = 2) from 4 sources, i.e. Gleick, 1993; LeCornu, 1998; Torcellini et al., 2003 & Mielke et al., 2010.

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

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.*

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’

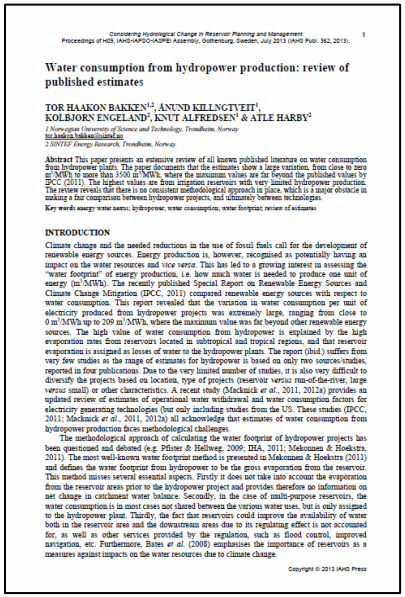
- Potentially a large reputational and business risk
- Might disqualify hydropower based on an unfair methodological basis
- The water footprint methodology seems to gain an increasing foothold

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).



Considering Hydrological Change in Reservoir Planning and Management
Proceedings of H09, IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, July 2013 (IAHS Publ. 362, 2013). 1

Water consumption from hydropower production: review of published estimates

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Abstract This paper presents an extensive review of all known published literature on water consumption from hydropower plants. The paper documents that the estimates show a large variation, from close to zero m³/MWh to more than 3500 m³/MWh, where the maximum values are far beyond the published values by IPCC (2011). The highest values are from irrigation reservoirs with very limited hydropower production. The review reveals that there is no consistent methodological approach in place, which is a major obstacle in making a fair comparison between hydropower projects, and ultimately between technologies.

Key words energy; water issues; hydropower; water consumption; water footprint; review of estimates

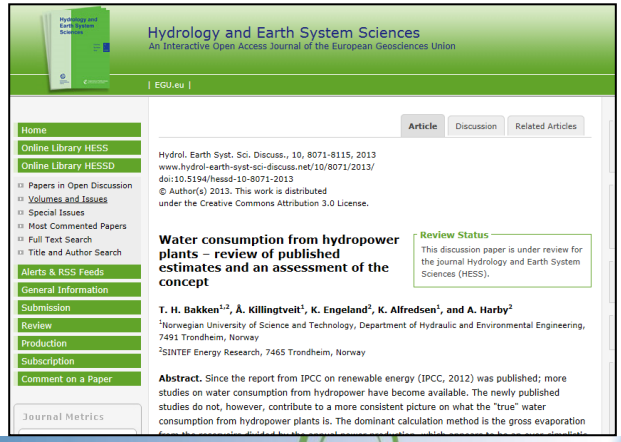
INTRODUCTION

Climate change and the needed reductions in the use of fossil fuels call for the development of renewable energy sources. Energy production is, however, recognised as potentially having an impact on the water resources and vice versa. This has led to a growing interest in assessing the "water footprint" of energy production, i.e. how much water is needed to produce one unit of energy (m³/MWh). The recently published Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC, 2011) compared renewable energy sources with respect to water consumption. This report revealed that the variation in water consumption per unit of electricity produced from hydropower projects was extremely large, ranging from close to 0 m³/MWh up to 209 m³/MWh, where the maximum value was far beyond other renewable energy sources. The high value of water consumption from hydropower is explained by the high evaporation rates from reservoirs located in subtropical and tropical regions, and that reservoir evaporation is assigned as losses of water to the hydropower plants. The report (ibid.) suffers from very few studies as the range of estimates for hydropower is based on only two sources/studies, reported in four publications. Due to the very limited number of studies, it is also very difficult to diversify the projects based on location, type of projects (reservoir *versus* run-of-the-river, large *versus* small) or other characteristics. A recent study (Mackinck *et al.*, 2011, 2012a) provides an updated review of estimates of operational water withdrawal and water consumption factors for electricity generating technologies (but only including studies from the US. These studies (IPCC, 2011; Mackinck *et al.*, 2011, 2012a) all acknowledge that estimates of water consumption from hydropower production faces methodological challenges.

The methodological approach of calculating the water footprint of hydropower projects has been questioned and debated (e.g. Pfister & Hellweg, 2009; IEA, 2011; Mekonnen & Hoekstra, 2011). The most well-known water footprint method is presented in Mekonnen & Hoekstra (2011) and defines the water footprint from hydropower to be the gross evaporation from the reservoir. This method misses several essential aspects. Firstly it does not take into account the evaporation from the reservoir areas prior to the hydropower project and provides therefore no information on net change in catchment water balance. Secondly, in the case of multi-purpose reservoirs, the water consumption is in most cases not shared between the various water uses, but is only assigned to the hydropower plant. Thirdly, the fact that reservoirs could improve the availability of water both in the reservoir area and the downstream areas due to its regulating effect is not accounted for, as well as other services provided by the regulation, such as flood control, improved navigation, etc. Furthermore, Bates *et al.* (2008) emphasises the importance of reservoirs as a measures against impacts on the water resources due to climate change.

2

Hydrology and Earth System Sciences (2013)



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doi:10.5194/hessd-10-8071-2013

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

Review Status
This discussion paper is under review for the journal Hydrology and Earth System Sciences (HESS).

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Abstract. Since the report from IPCC on renewable energy (IPCC, 2012) was published; more studies on water consumption from hydropower have become available. The newly published studies do not, however, contribute to a more consistent picture on what the "true" water consumption from hydropower plants is. The dominant calculation method is the gross evaporation

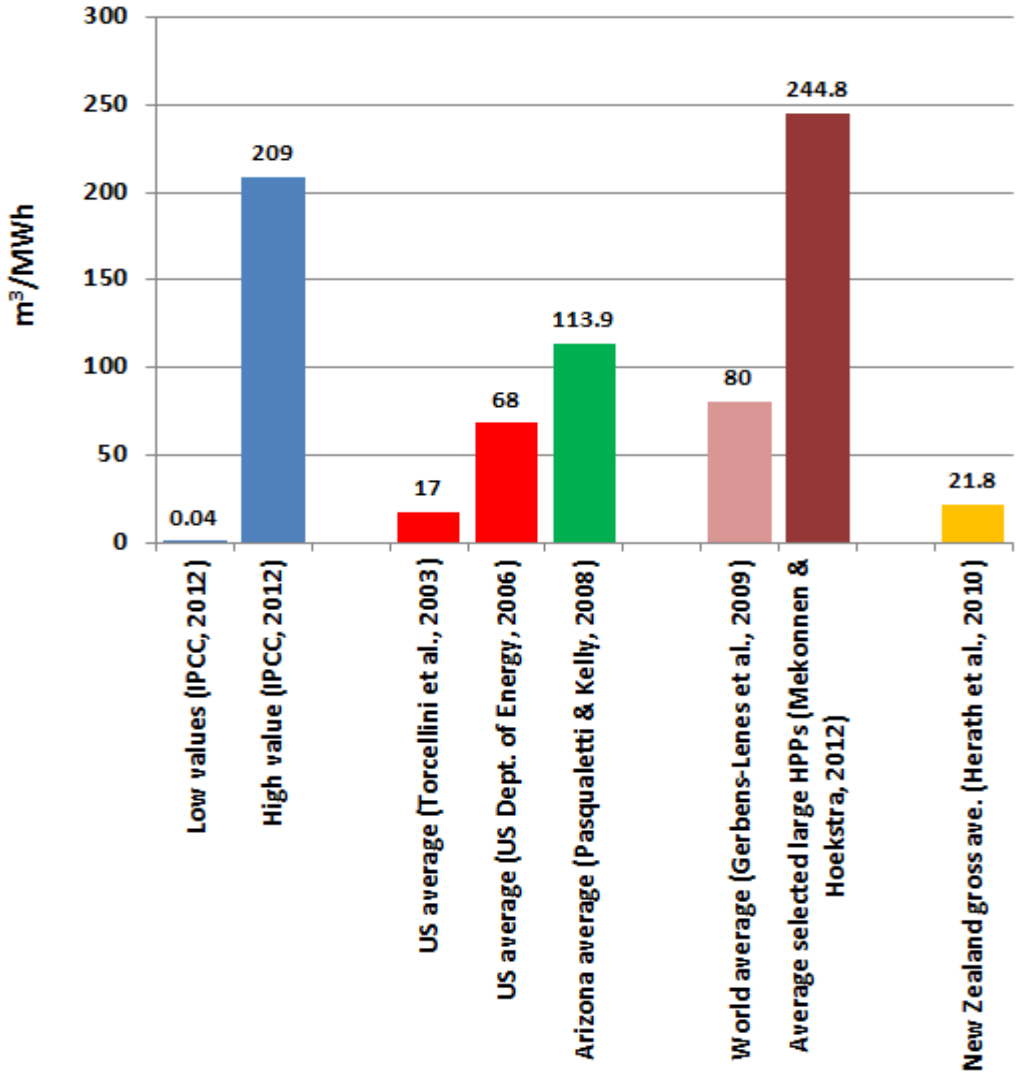
Basis for calculations

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

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

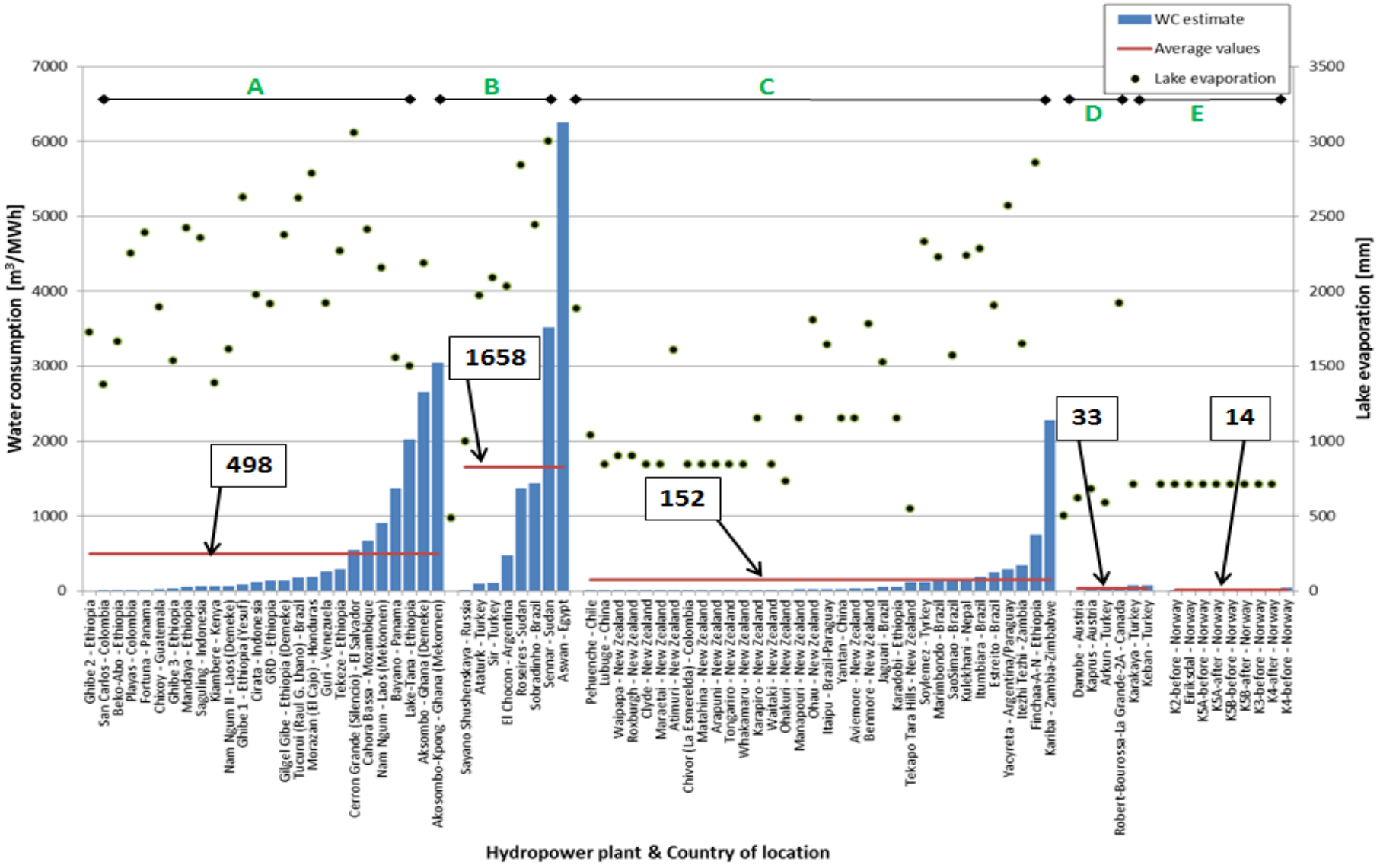
3. $$Water\ balance = \frac{Evaporation\ reservoir - Direct\ rainfall\ reservoir}{Annual\ power\ production}$$

Selected benchmarks published – Gross values

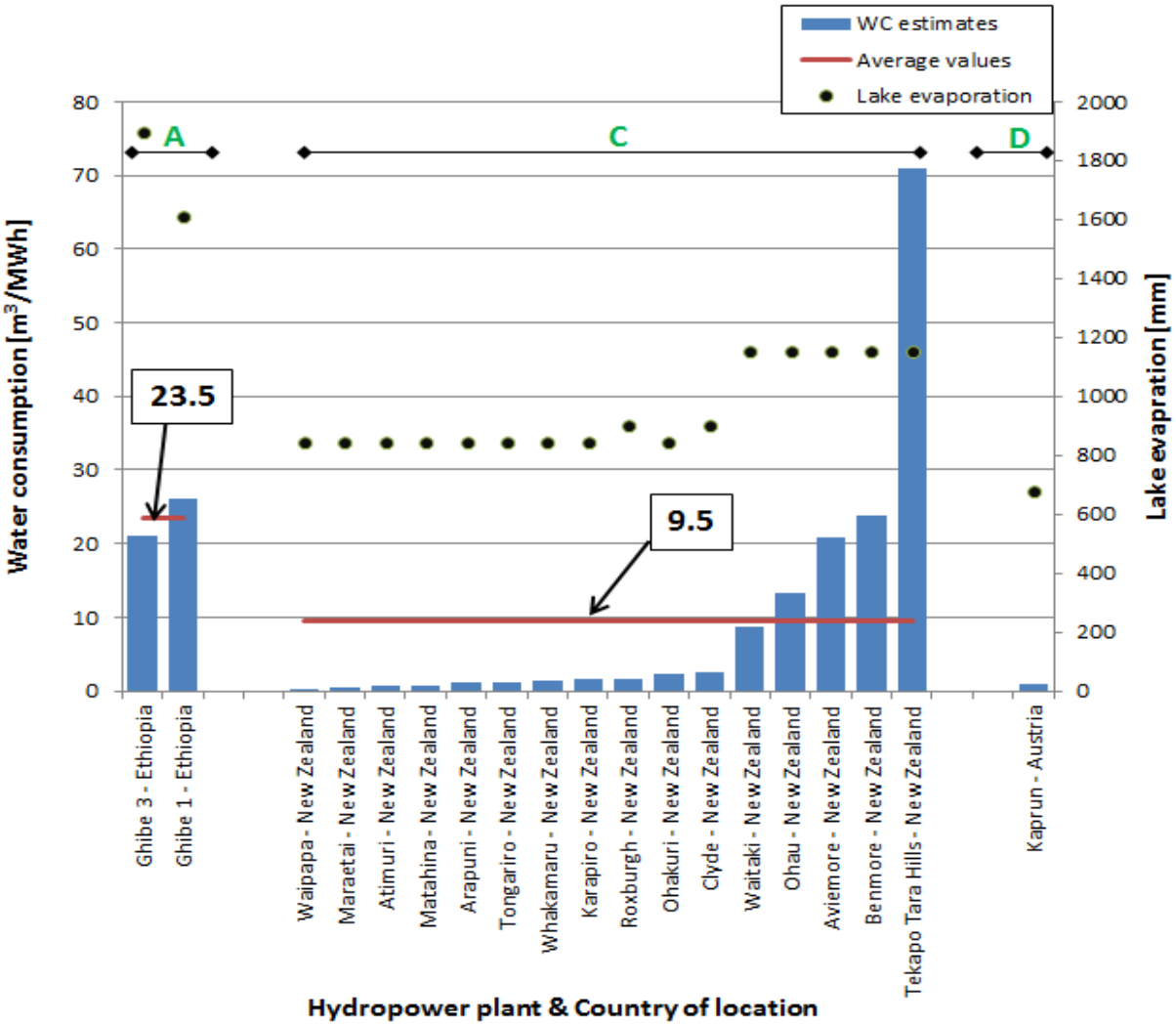


- 'IPCC-values'
- US averages, based on 2 different datasets
- World average based on 2 different datasets
- 2 regional averages (Arizona and NZ)

Single-plant studies – Gross values



Single-plant studies – Net values



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 (2011).
- 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 (1/3)

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.

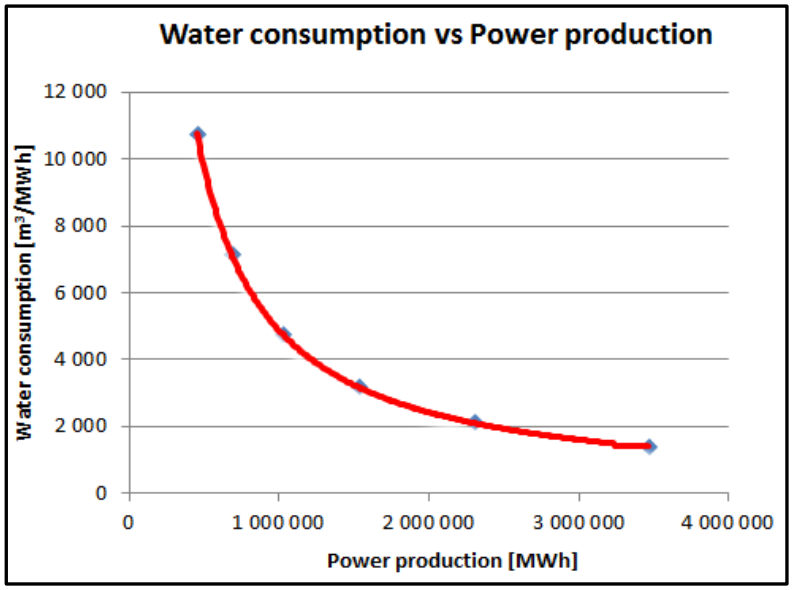
3. Impacts from the water consumption/footprint is ‘ignored’.

4. Construction of dams is a very common way to improve the availability of/access to water. Are reservoirs in arid regions not feasible due to high water footprints?

Critique: Methodological problems (2/3)

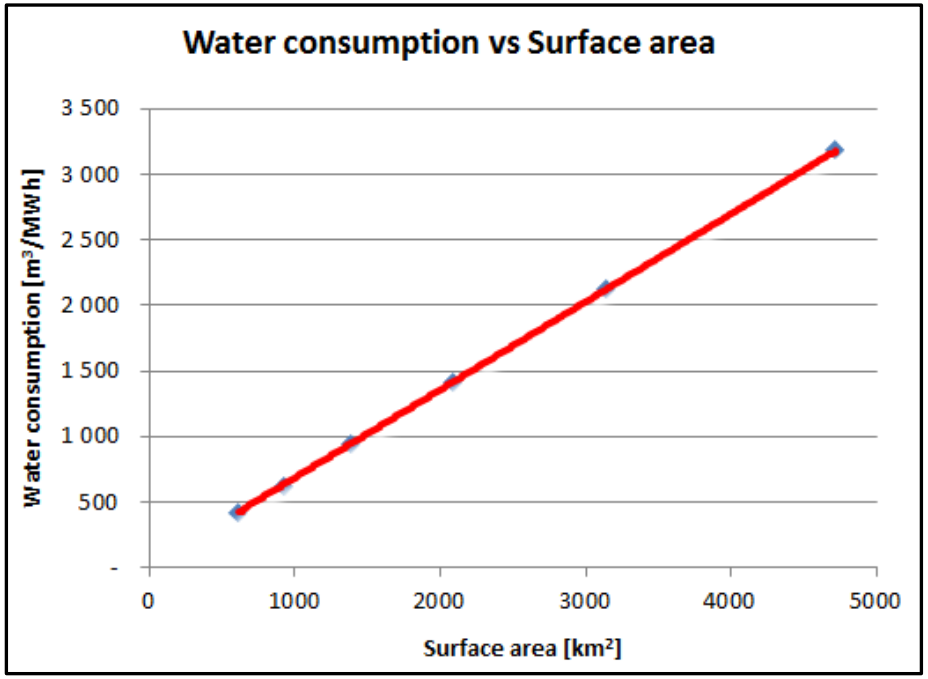
5. How to set the right system boundaries in space and time?

   - 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?



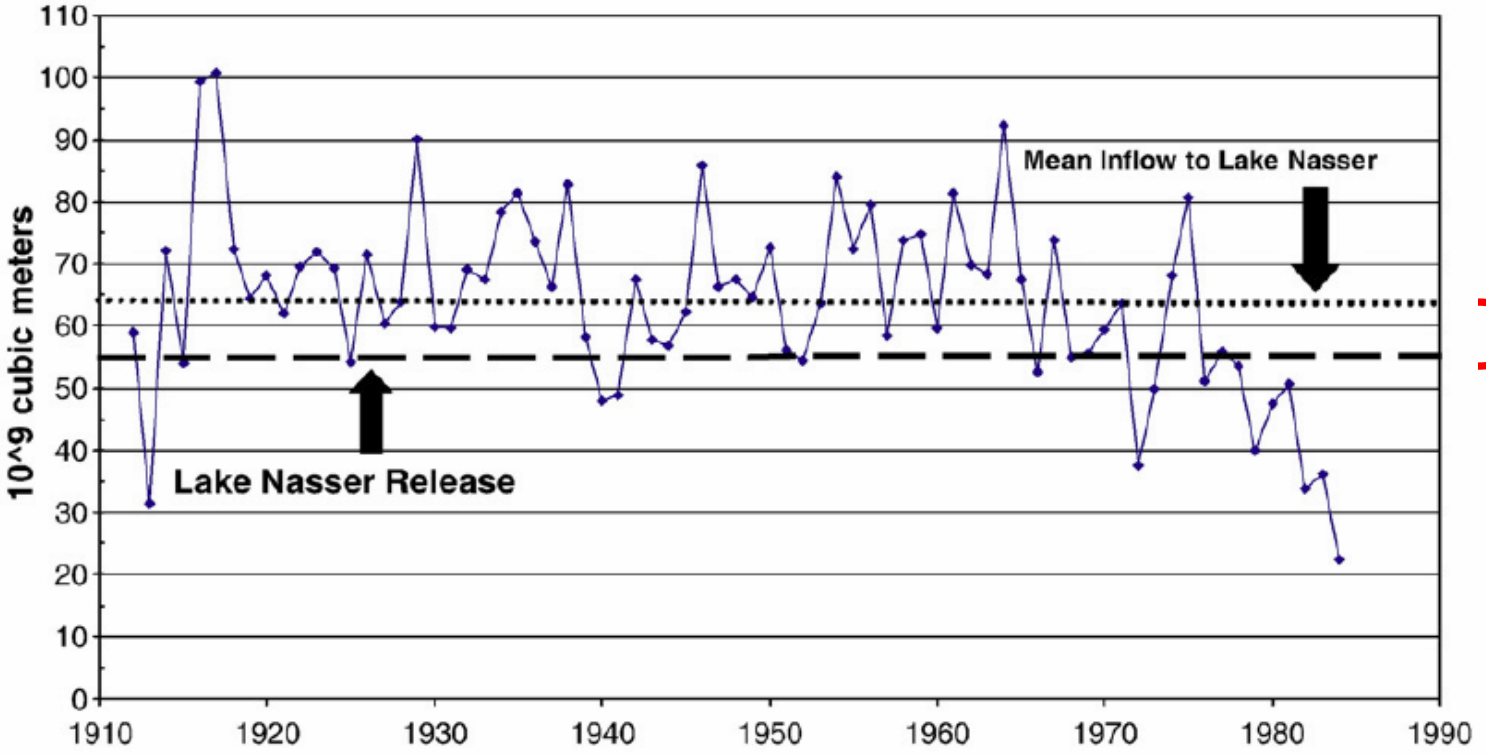
Critique: Methodological problems (3/3)

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



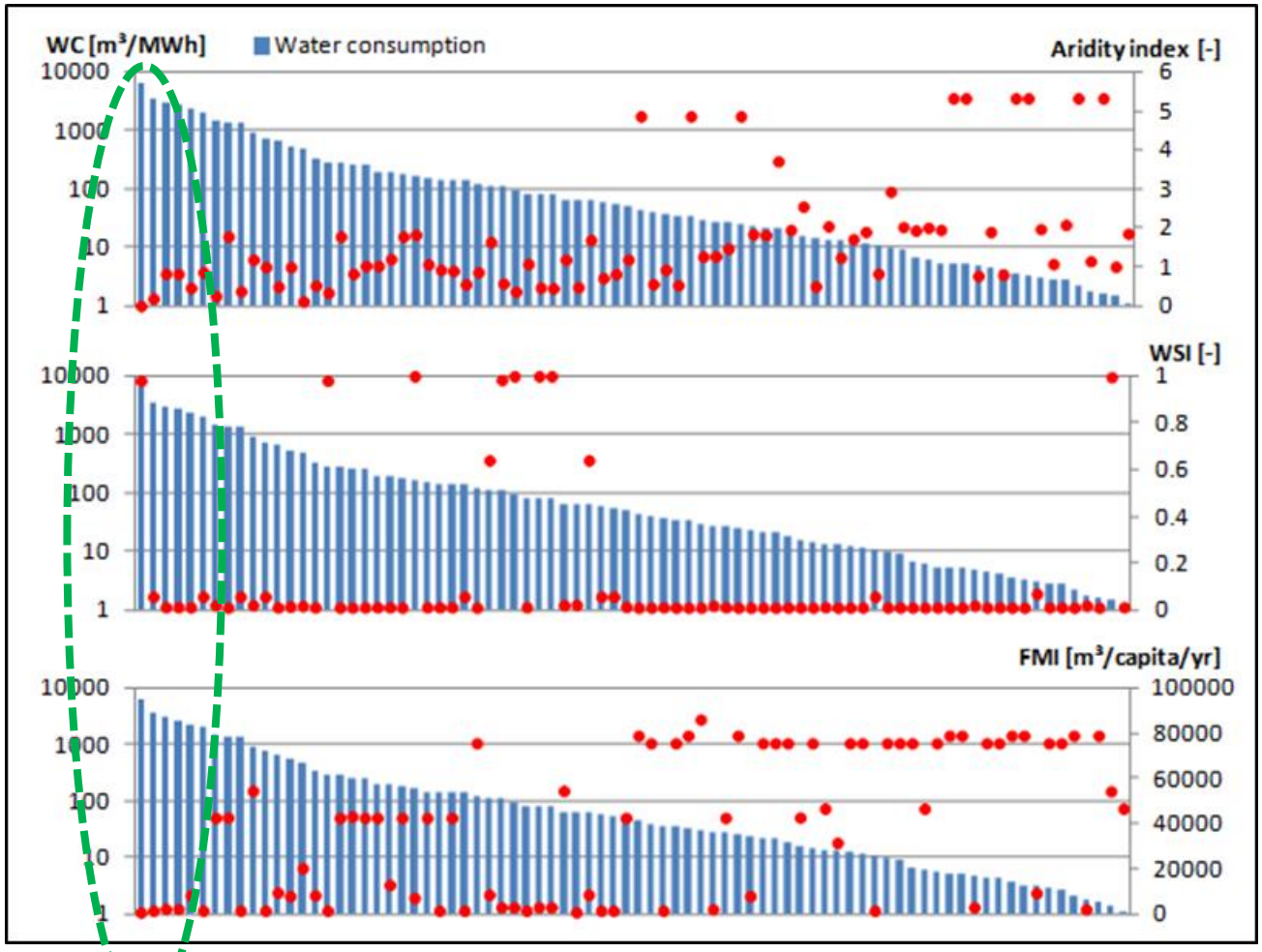
7. Withdrawal versus consumption?

Inflow and outflow Lake Nasser/High Aswan Dam, Egypt



Source: Strzepek et al. 2008

Would you avoid reservoirs in arid areas if high water footprints?



Hydropower water consumption (WC) estimates (n=80) presented as blue bars in the relation to aridity index in the upper pan, water stress index (WSI) in the center pan and Falkenmark index (FMI) in the lower pan. (Weichert, 2013).

Characteristics of the High Aswan Dam (Egypt)

- The reservoir has a storage capacity of 162 km^3
- High Aswan Dam is a multipurpose project and the main reason for construction was to develop irrigation systems for increasing rice and sugar-cane cultivation.
- The construction of the dam enabled perennial irrigation, whereby water is available at any time throughout the year.
- Other objectives enabled by flow regulation of the Nile River are flood protection, hydroelectricity generation and improved navigation.
- Evaporation rates approx. 3000 mm/yr
- Has a very high water consumption, i.e. 6250 m^3/MWh (due to high evaporation) according to Demeke et al. (2013).

The value of the high Aswan Dam to the Egyptian economy

The risk premium on the reduced variability in flow is estimated to be:

- *EGP 1.1 billion for a modest risk aversion, and perhaps EGP 4.4 billion for a high risk aversion.*
- *The total gain of EGP 7.1 billion to 10.3 EGP billion equals 2.7% to 4.0% of annual GDP in 1997.*

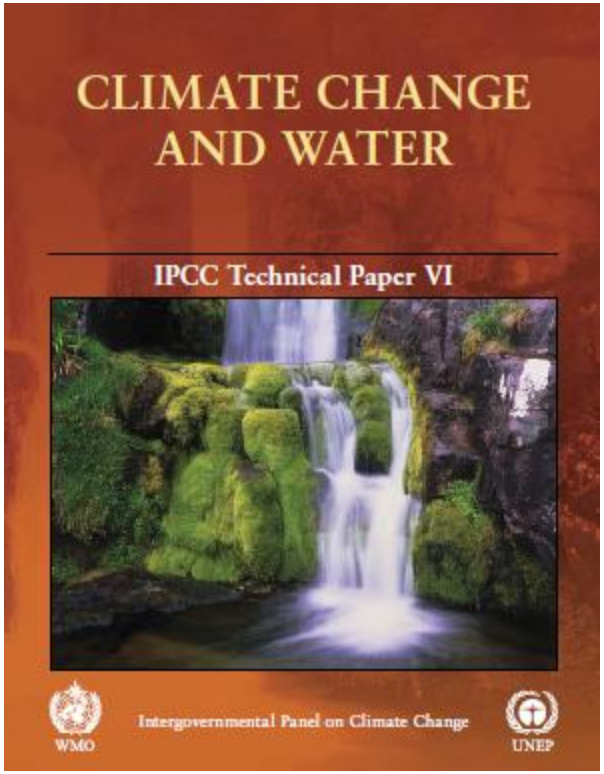
Source: Strzepek et al. 2008

Climate change and reservoirs

Reservoirs are acknowledged as an important part of the infrastructure in order to cope with climate change to secure water supply in the future (Bates et al., 2008).

In many regions climate changes will reduce precipitation further and additional reservoirs are necessary (Harman et al., 2005).

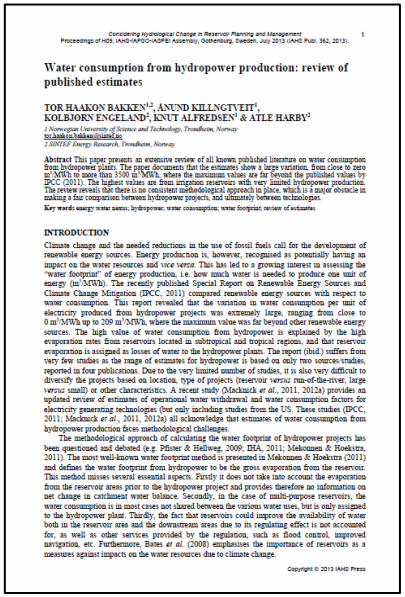
Climate change and population growth call for more efficient and better strategies in management of water, i.e. more, better designed and operated reservoirs.



Summed up

- The recently published values vary a lot and new studies are even far beyond values published by IPCC (2011).
- 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



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Key words energy; water nexus; hydropower; water consumption; water footprint; review of estimates

INTRODUCTION

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

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Abstract

Access to sufficient quantities of water of acceptable quality is a basic need for human beings and a pre-requisite to sustain and develop human welfare. In cases of limited availability, the allocation of water between different sectors can result in conflicts of interests. In this study, a modified version of the Building Block Methodology (BBM) was demonstrated for allocation of waters between different sectors. The methodology is a workshop-based tool for assessing water allocation between competing sectors that requires extensive stakeholder involvement. The tool was demonstrated for allocation of water in the Sri Ram Sagar water reservoir in the Godavari Basin, Andhra Pradesh, India. In this multipurpose reservoir, water is used for irrigation, drinking water supply and hydropower production. Possible water allocation regimes were developed under present hydrological conditions (normal and dry years) and under future climate change, characterized by more rain in the rainy season, more frequent droughts in the dry season and accelerated siltation of the reservoir, thus reducing the storage capacity. The feedback from the stakeholders (mainly water managers representing the various sectors) showed that the modified version of the BBM was a practical and useful tool in water allocation, which means that it may be a viable tool for application also elsewhere.

Keywords: optimal water allocation, building block methodology (BBM), climate change, Godavari Basin, India

1. Introduction

Water is essential for all types of basic services, such as food production, supply of drinking water, health and sanitation services, industrial production and for sustaining the earth's ecosystems. In India, investments in the water sector have primarily focused on irrigation projects with the aim to expand the area under irrigated agriculture and increase the food production. Other sectors also experience growing needs, such as drinking water supply, process-water to the industry, water for hydropower production, water to secure navigation and for recreational services (Amerasinghe et al., 2005; Chitale, 2005). There are also inherent dependencies between some of the water uses, exemplified by the fact that the majority of irrigation projects in India have provisions for generation of power. The availability of water is to a large extent dependent on climatological and hydrological characteristics, and the water resources in India are not evenly distributed in time and space (Gosain et al., 2006; Kakumanu, 2009). One part of the country might experience floods and water logging problems, while other parts might need to cope with droughts and scarcity at the same time. In periods when the need for water is larger than the supply, practical tools to assist in the allocation of water between competing sectors can be useful. Such tools may also reduce the tension between the different interests.

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).

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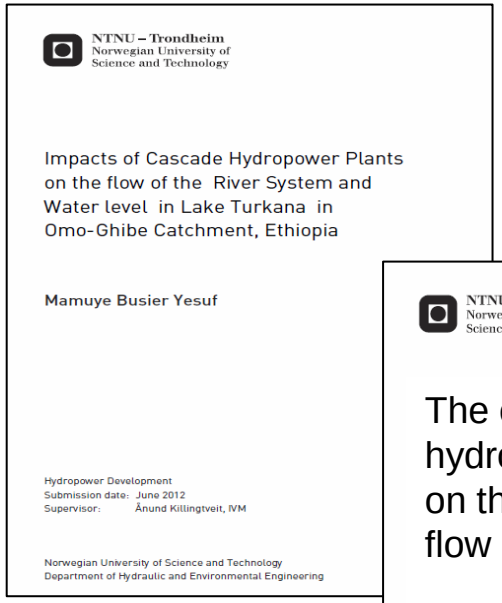
Documentation

Master: Lake Turkana



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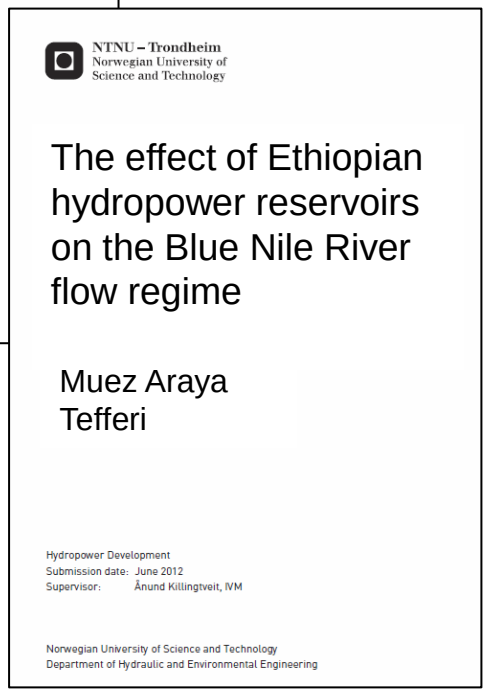
Impacts of Cascade Hydropower Plants on the flow of the River System and Water level in Lake Turkana in Omo-Ghibe Catchment, Ethiopia

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

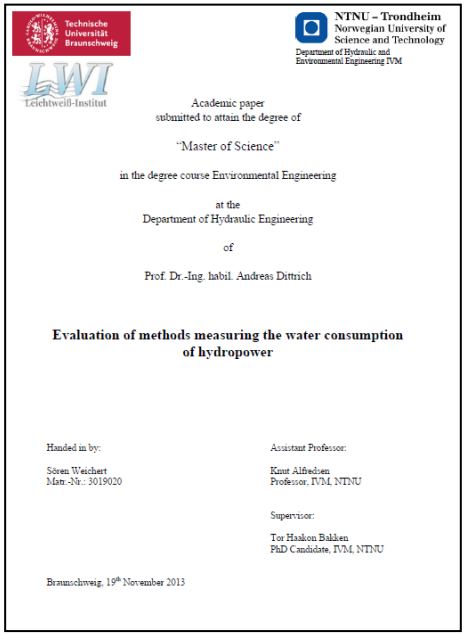
The effect of Ethiopian hydropower reservoirs on the Blue Nile River flow regime

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:

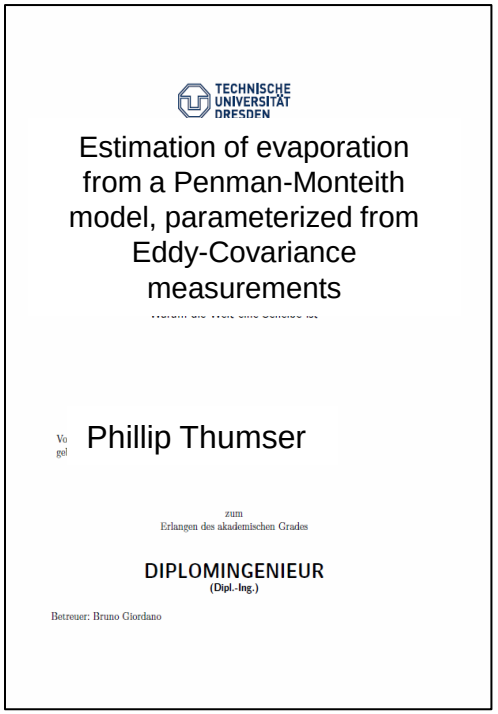
Knut Alfredsen
Professor, IVM, NTNU

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

Vo
gel

Phillip Thumser

zum
Erlangen des akademischen Grades

DIPLOMINGENIEUR
(Dipl.-Ing.)

Betreuer: Bruno Giordano