

# Water consumption from hydropower production: review of published estimates

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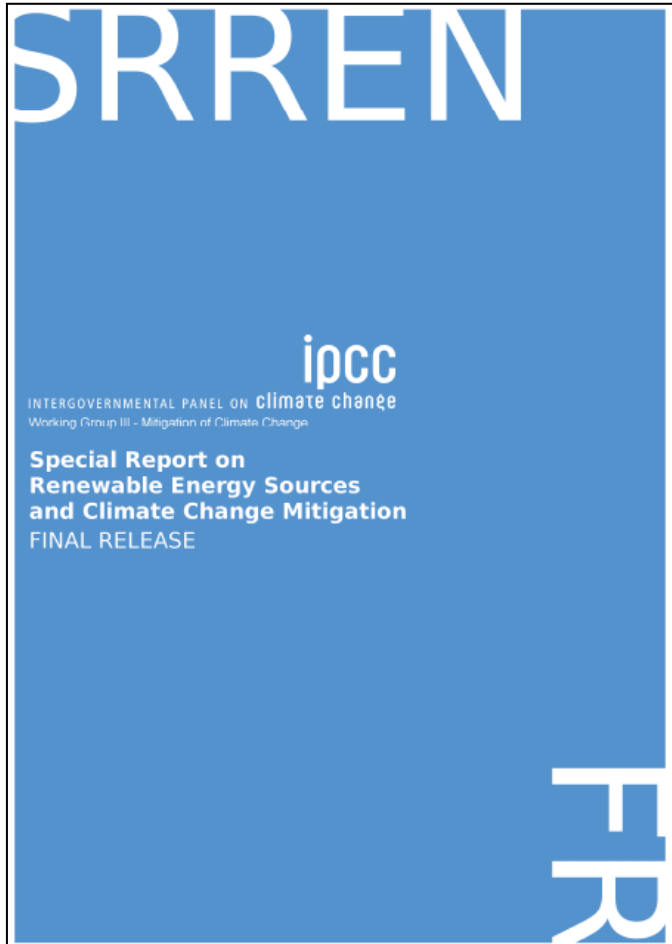
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# Structure of talk

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



# What raised the attention?



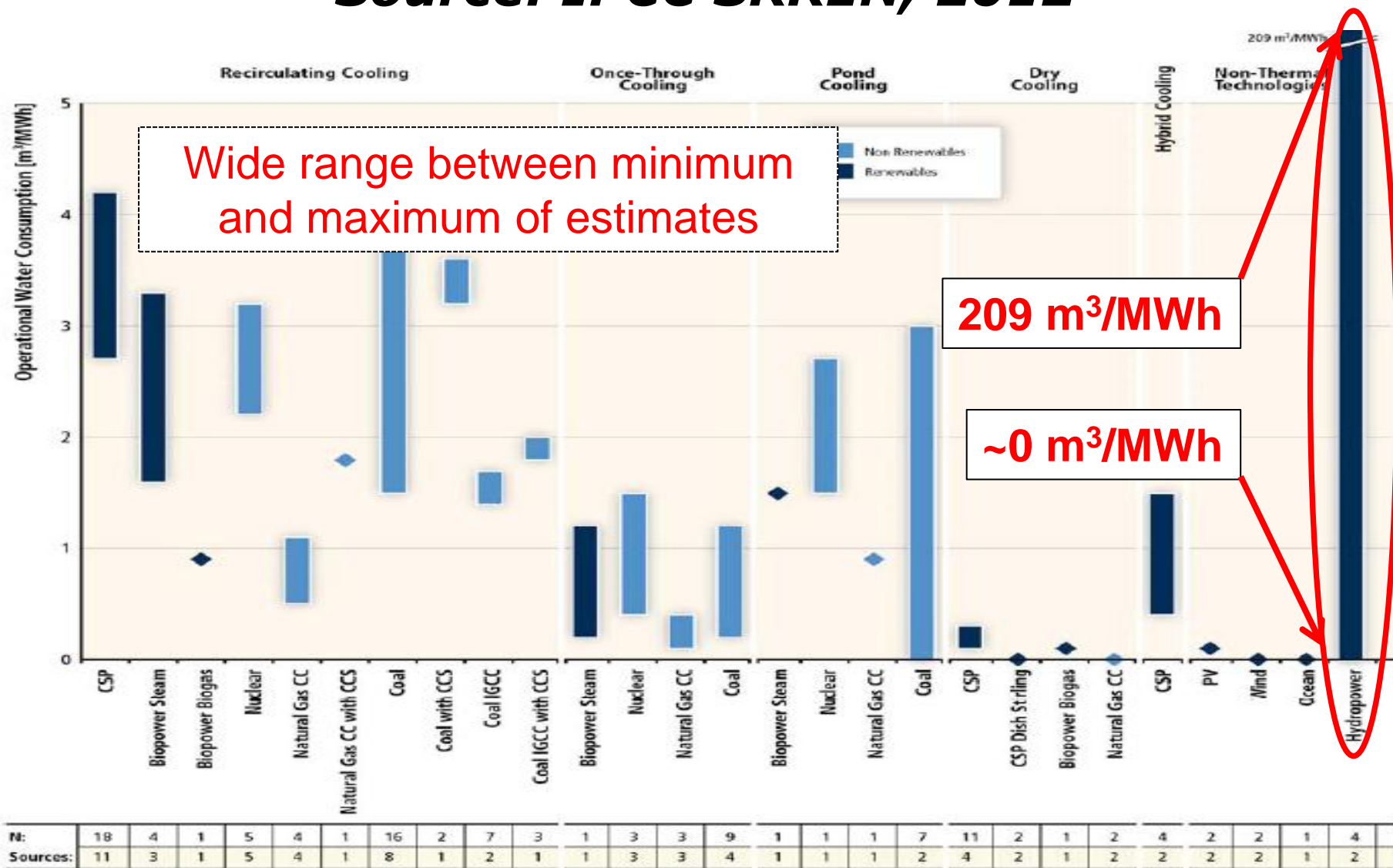
IPCC Special Report on Renewable Energy (2012):

- 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*)'



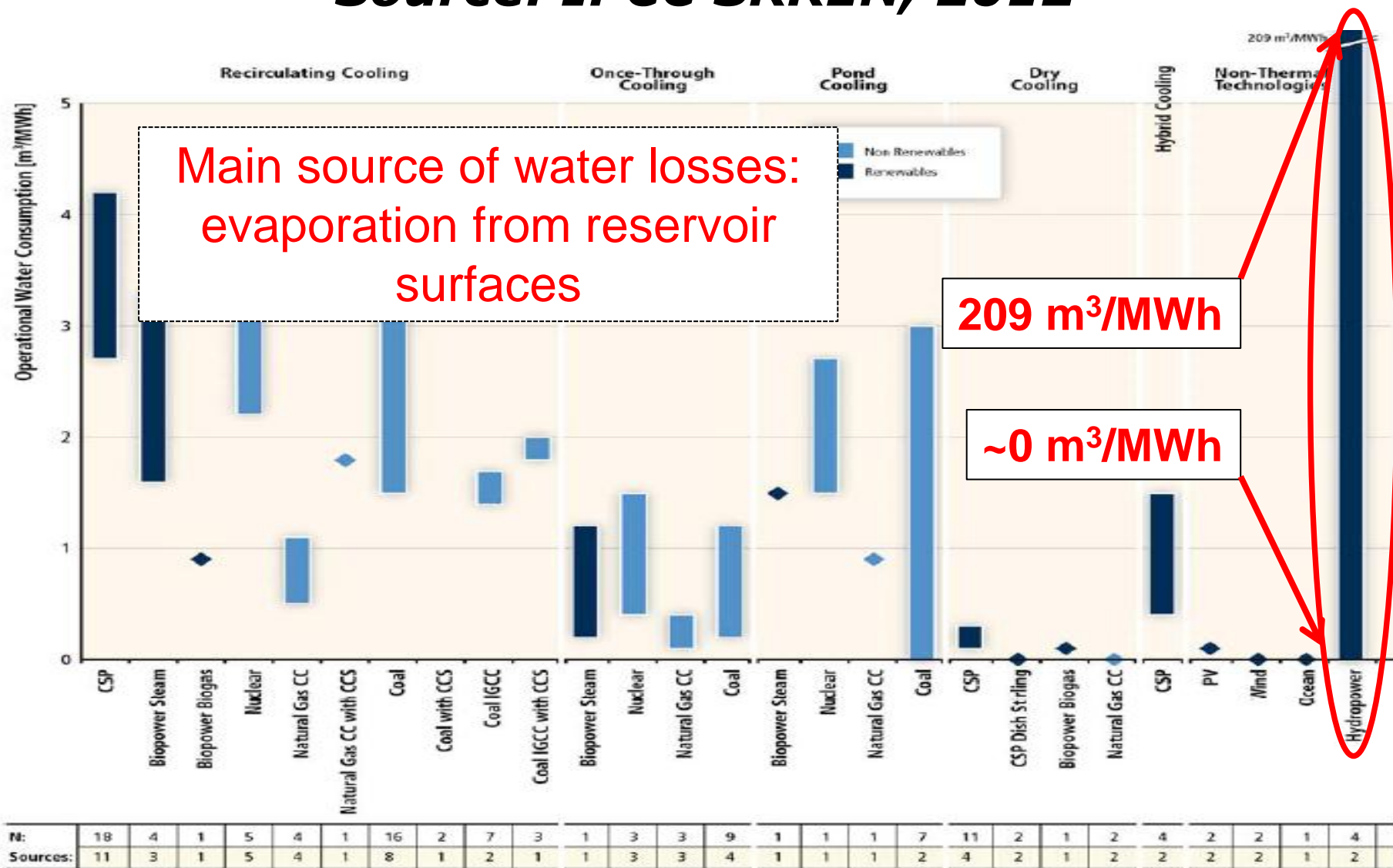
# Water consumption from energy generation:

**Source: IPCC SRREN, 2012**



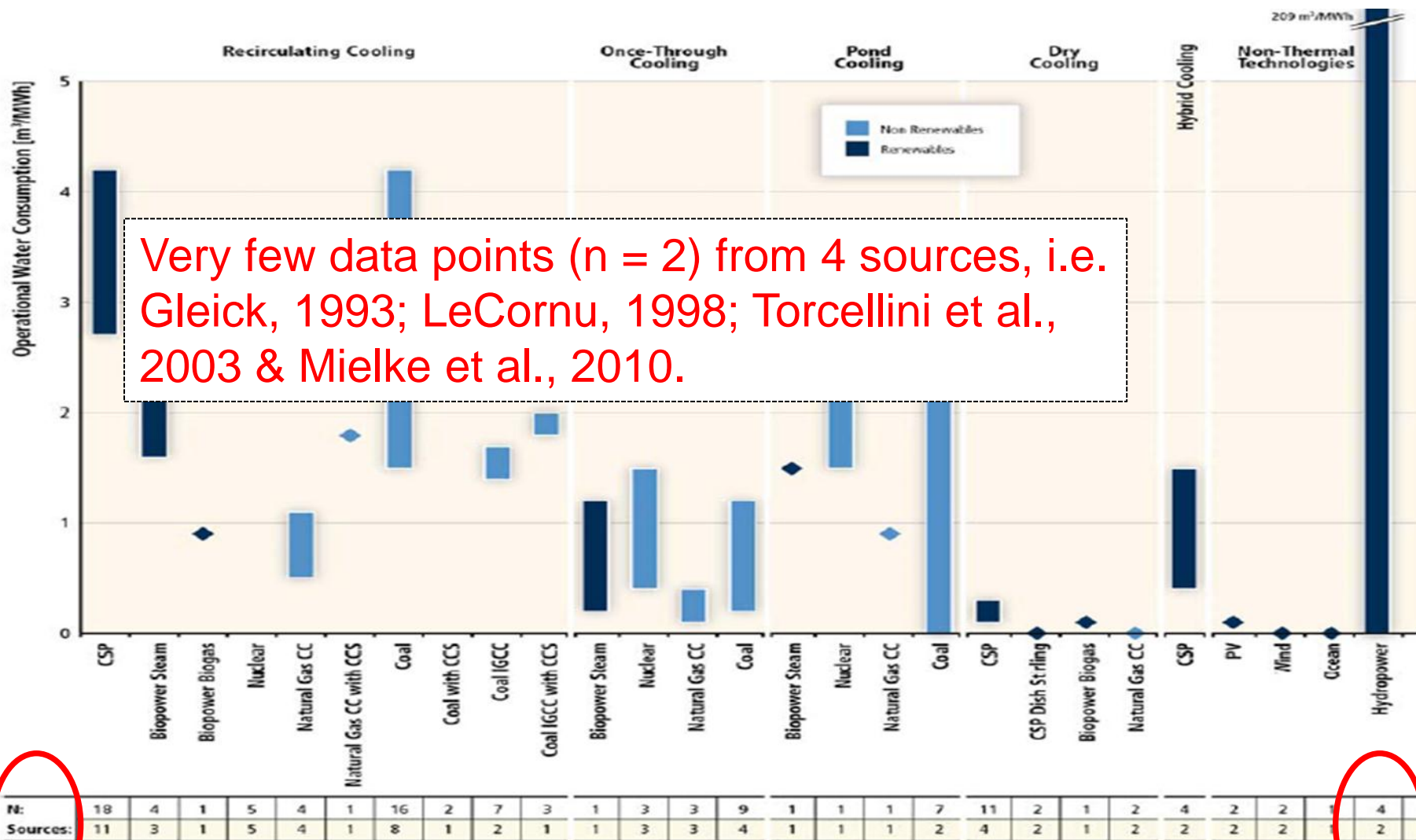
# Water consumption from energy generation:

**Source: IPCC SRREN, 2012**



# Water consumption from energy generation:

**Source: IPCC SRREN, 2012**



# 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

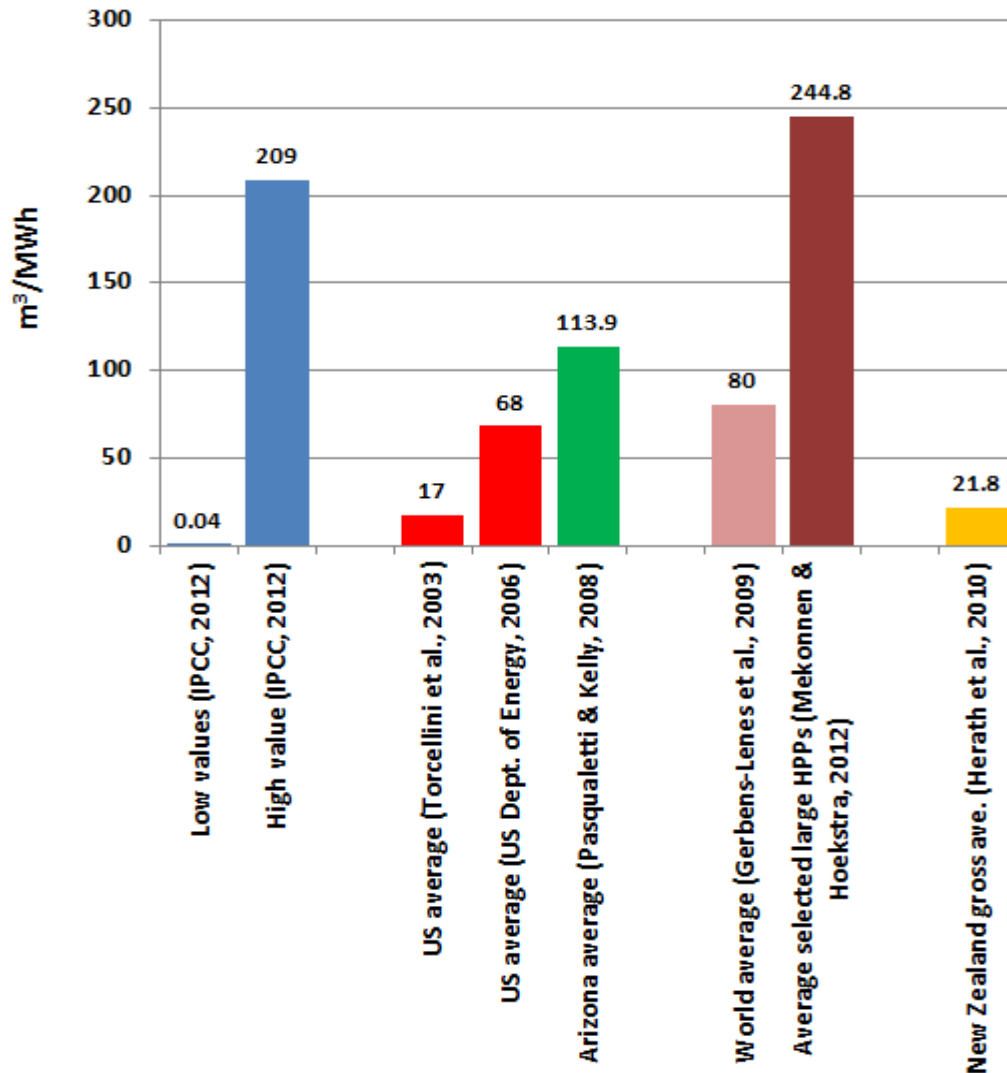
HESS Discussion (open until August 19<sup>th</sup>, 2013):

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

# Basis for calculations

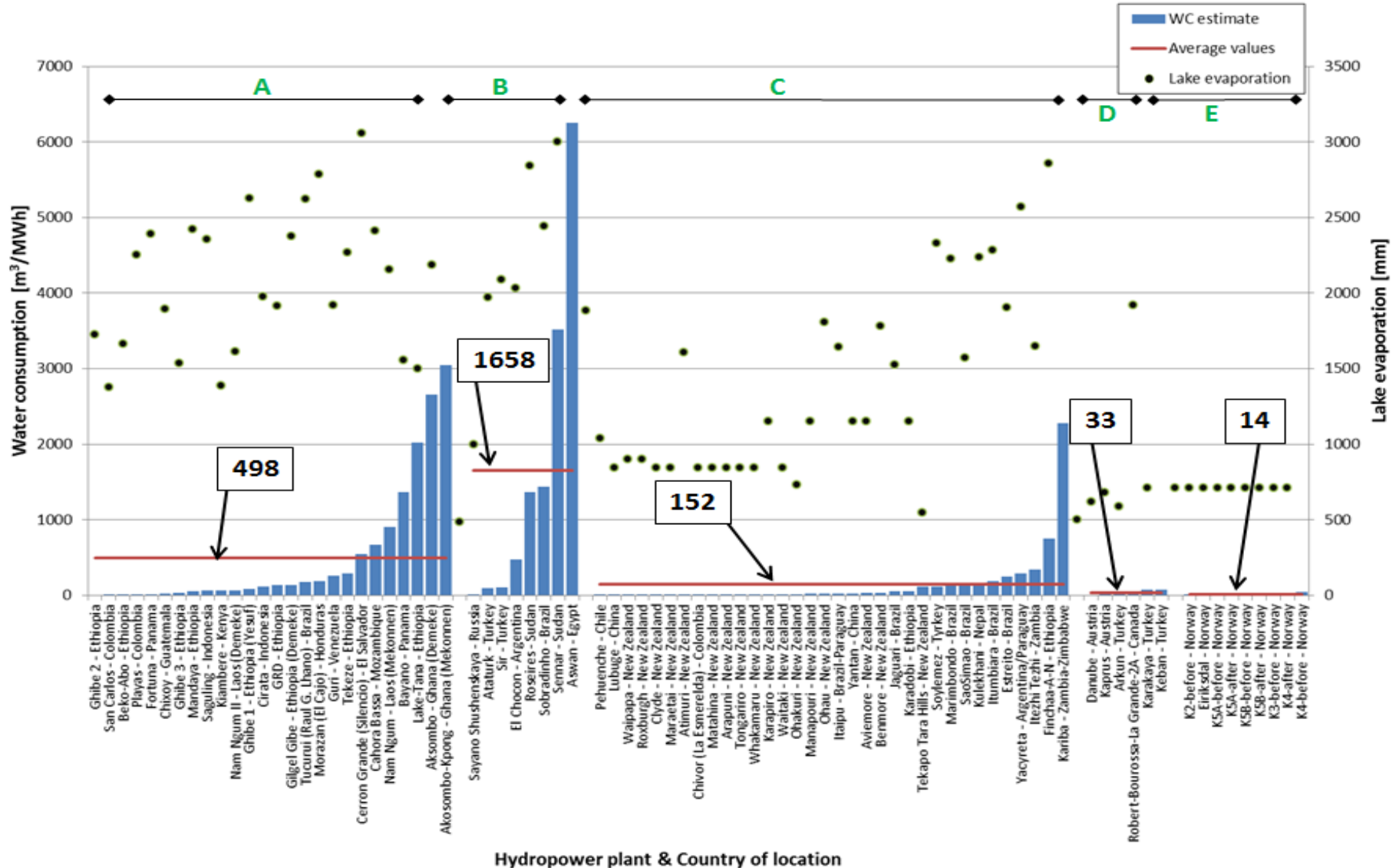
1. 
$$\text{Gross water consumption} = \frac{\text{Evaporation reservoir}}{\text{Annual power production}}$$
2. 
$$\text{Net water consumption} = \frac{\text{Evaporation reservoir} - \text{Evaporation before inundation}}{\text{Annual power production}}$$
3. 
$$\text{Water balance} = \frac{\text{Evaporation reservoir} - \text{Direct rainfall reservoir}}{\text{Annual power production}}$$

# Selected benchmarks published – Gross values



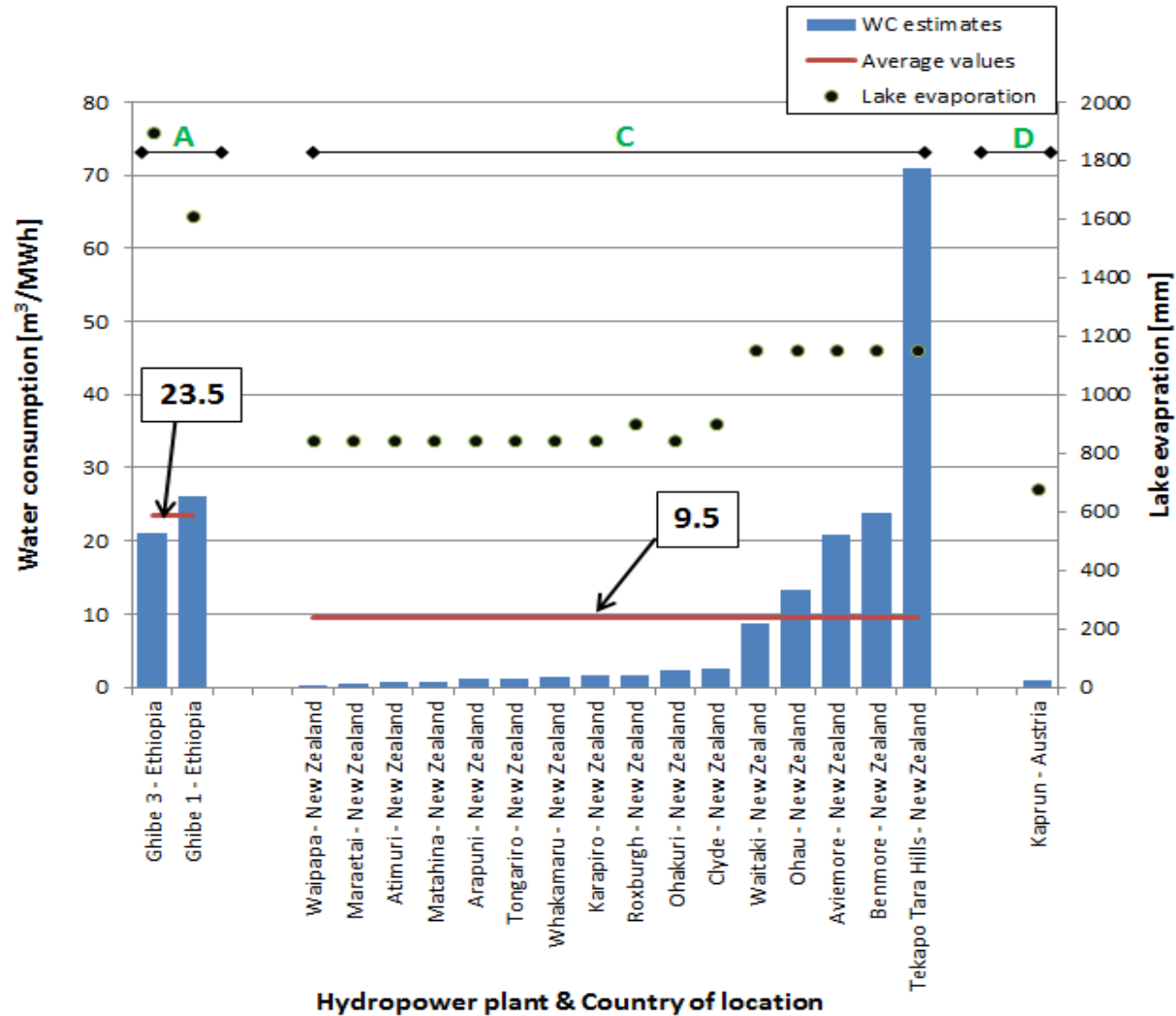
- ‘IPCC-values’
- US averages, based on 2 different datasets
- World average based on 2 different datasets
- 2 regional averages (Arizona and NZ)

# Single-plant studies – Gross values

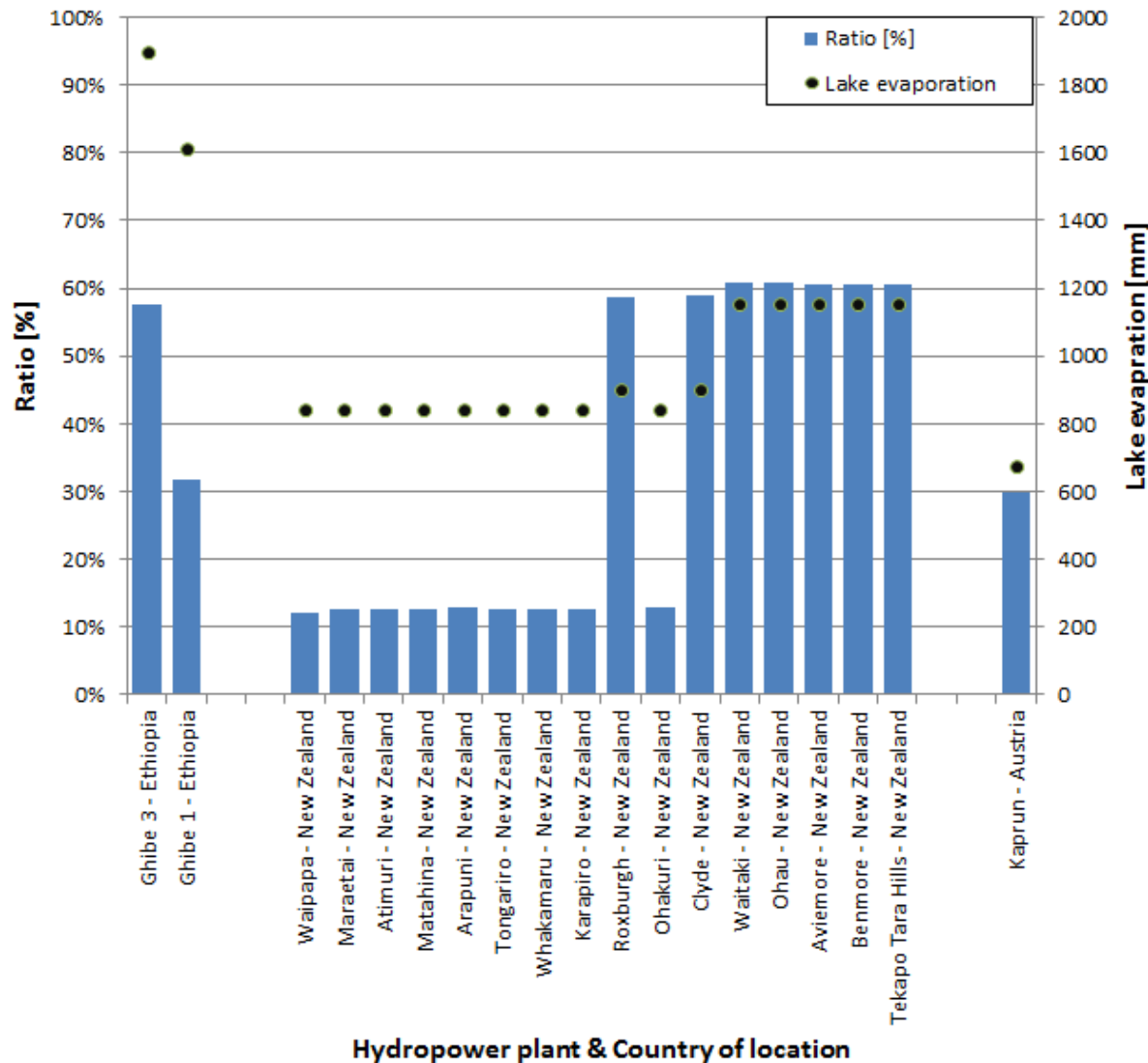




# Single-plant studies – Net values



# 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, 'smoothing 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)

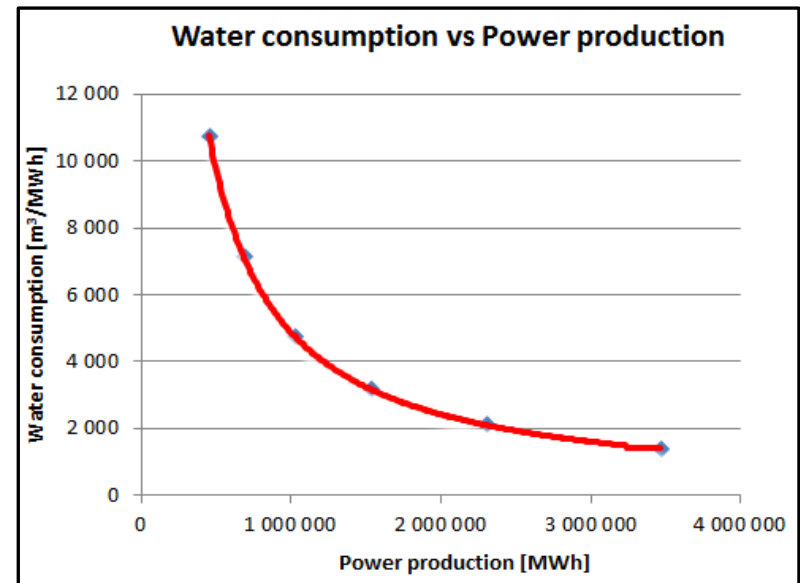
1. Values are given as gross evaporation from the reservoir area. For dams constructed on desert land, the net evaporation will be equal to the gross values, but in most cases evaporation will be less, especially for dams in wetland areas and areas with vegetation where the net increase may be very limited.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



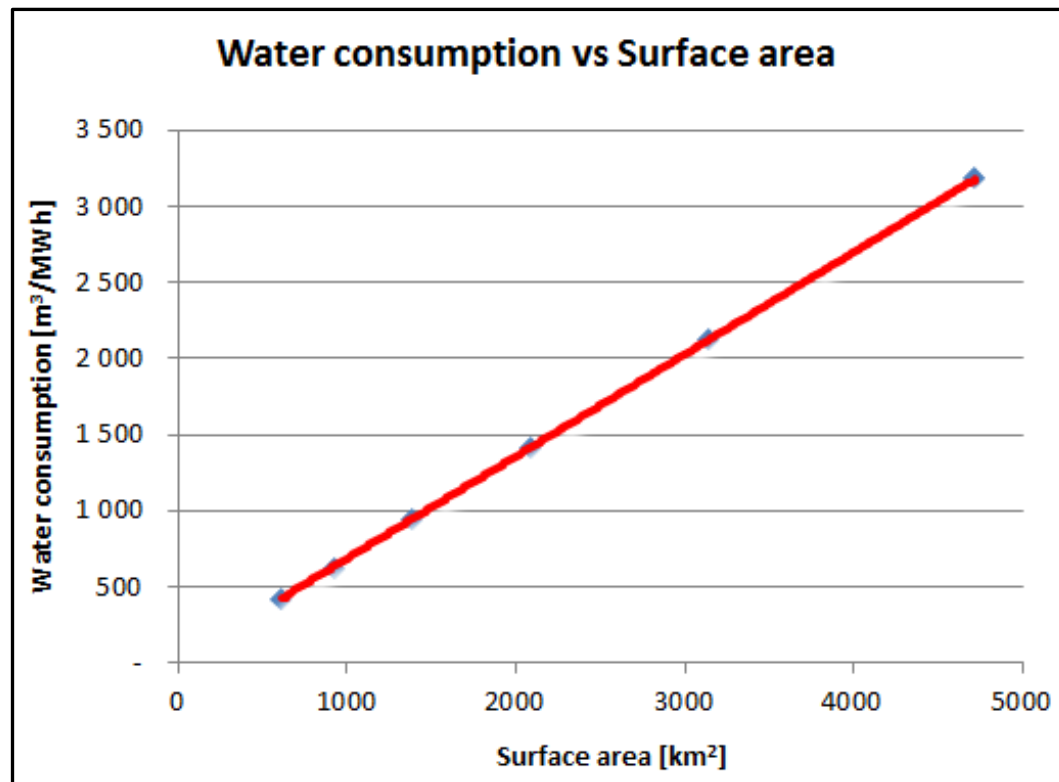
5. How to set the right system boundaries in space and time?

- 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?



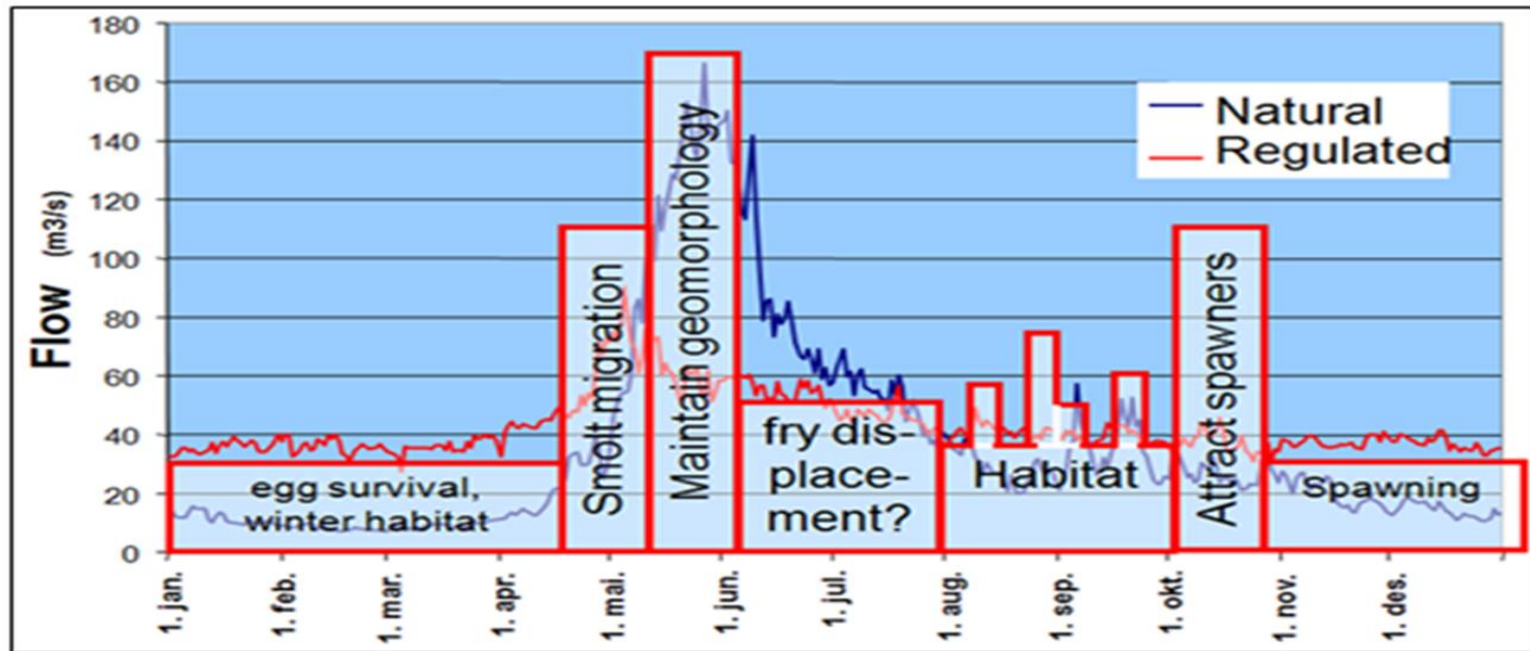
# Critique: Methodological problems (2/2)

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



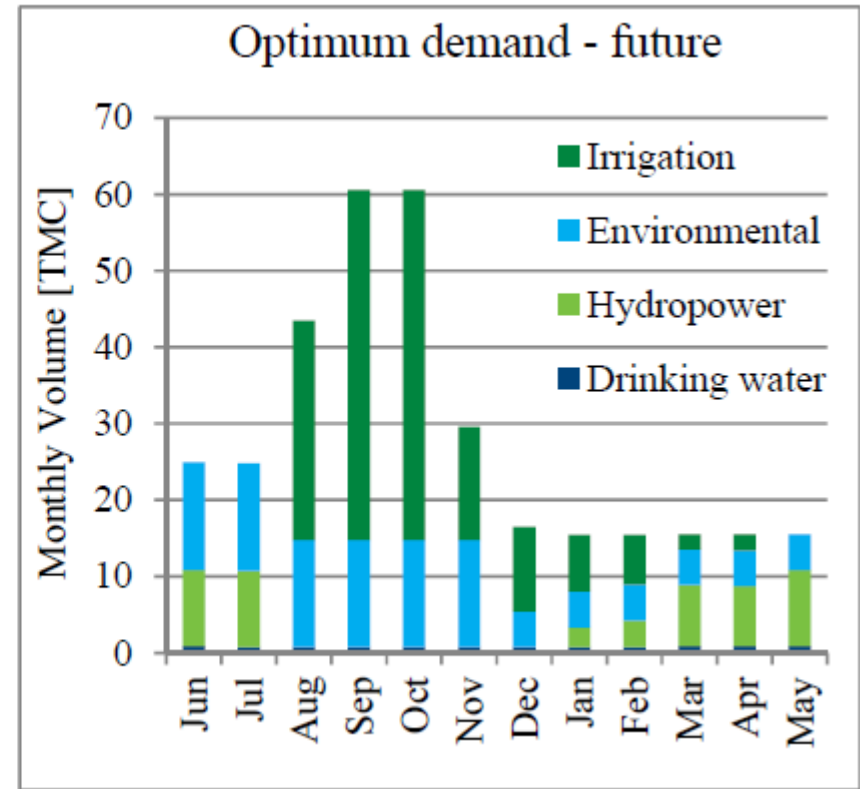
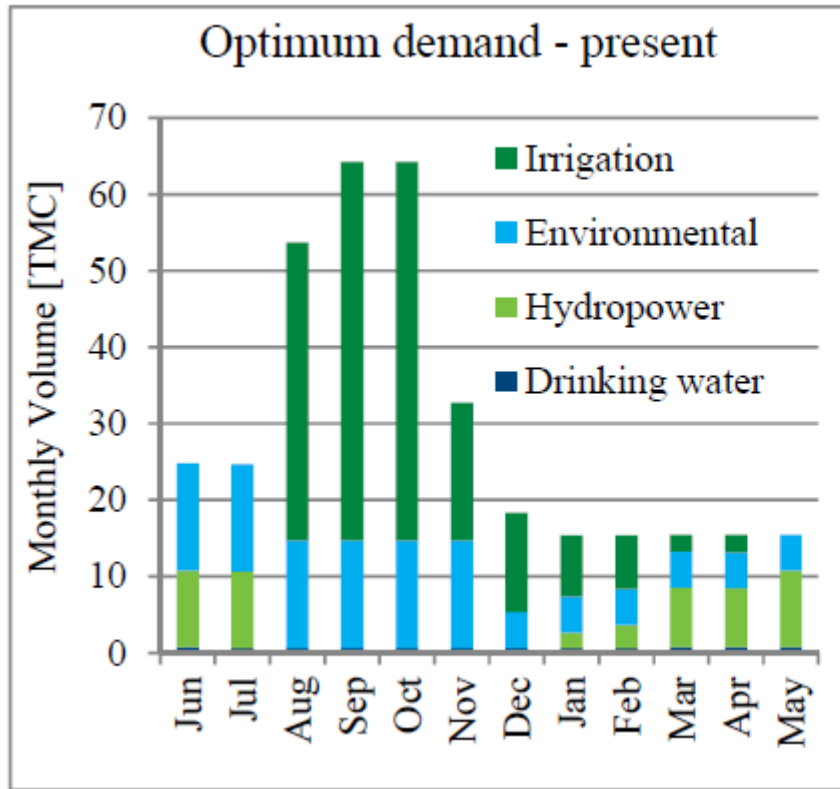


# How to describe the availability of water?



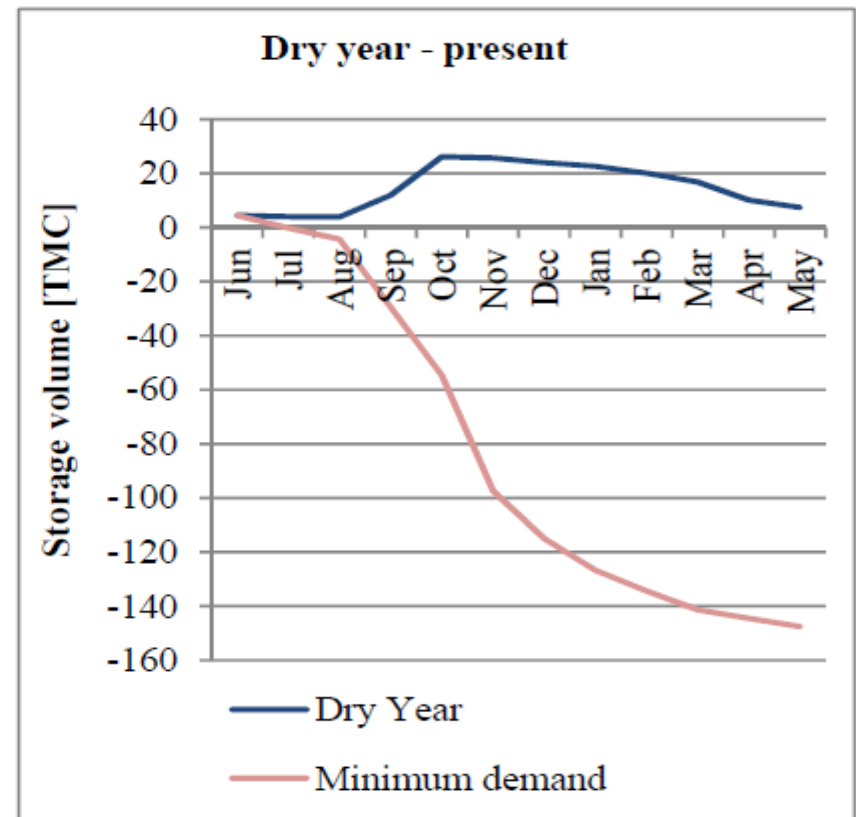
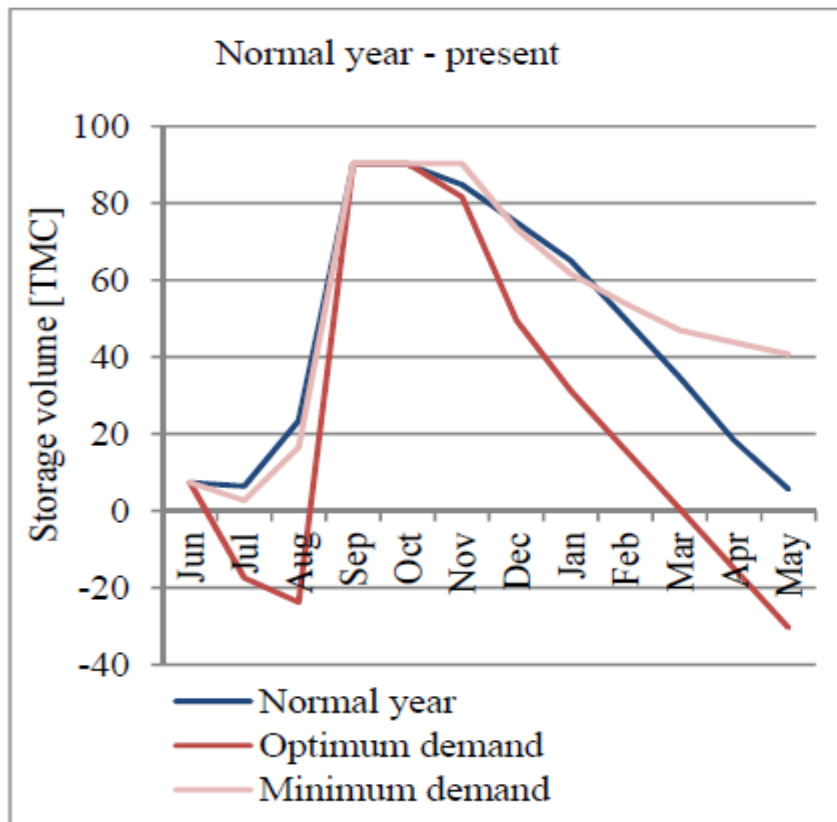
**Can the concept be transferred into finding the optimum water allocation in a setting of competing sectors interests?**

# 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

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

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 to 200 m<sup>3</sup>/MWh, where the maximum values are the lowest published values by IPCC (2011). The paper also shows that the estimates are very sensitive to the assumptions made. The review reveals that there is a consistent methodological approach in place, which is a major obstacle in making a comparison between hydropower projects, and ultimately between technologies.

**Key words:** energy, water, energy, water consumption, water footprint, review of estimates.

## INTRODUCTION

Climate change and the needed reduction 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 (in MWh). The recently published Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN, 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 m<sup>3</sup>/MWh up to 200 m<sup>3</sup>/MWh, where the maximum values were for 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 (SRREN) suffers from very few studies as the range of estimates for hydropower is based on only two source-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-river), large versus small or other characteristics. A recent study (Gleick et al., 2011, 2012) provides an updated review of estimates of operational water withdrawal and water consumption factors for electricity generating technologies (not only including studies from the US). These studies (IPCC, 2011; Gleick et al., 2011, 2012) 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. Priester & Hildner, 2009; EIA, 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 area prior to the hydropower project and provides therefore no information on net change in ambient water balance. Secondly, in the case of run-of-river projects, 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, Biele et al. (2002) emphasises the importance of reservoirs as a measure against impacts on the water resources due to climate change.

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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 interest. In this study, a modified version of the Building Block Methodology (BBM) was demonstrated for allocation of water 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 Pan Sagar 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, characterised 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 maintaining 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 (Amersingh et al. 2005; Chandra, 2002). 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. volume 6 (8).**

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

T. H. Bakken<sup>1,2</sup>, Å. Killingtveit<sup>1</sup>, K. Engeland<sup>2</sup>, K. Alfredsen<sup>1</sup>, and A. Harby<sup>2</sup>

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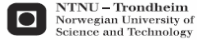
**Abstract.** Since the report from IPCC on renewable energy (IPCC, 2012) was published; more studies on water consumption from hydropower have become available. The newly published studies do not, however, contribute to a more consistent picture on the "true" water consumption from hydropower plants.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

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

**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. volume 17.**

## Master: Lake Turkana

# Documentation



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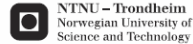
Impacts of Cascade Hydropower Plants  
on the flow of the River System and  
Water level in Lake Turkana in  
Omo-Ghibe Catchment, Ethiopia

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

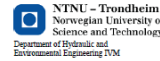
Hydropower Development  
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Supervisor: Ånund Killingtveit, IVM

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

## Master: Water indices



Technische  
Universität  
Braunschweig



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 Håakon Bakken  
PhD Candidate, IVM, NTNU

Braunschweig, 19<sup>th</sup> November 2013

## Master: Tydalen



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

Vo  
gel  
Phillip Thumser

zum  
Erlangen des akademischen Grades

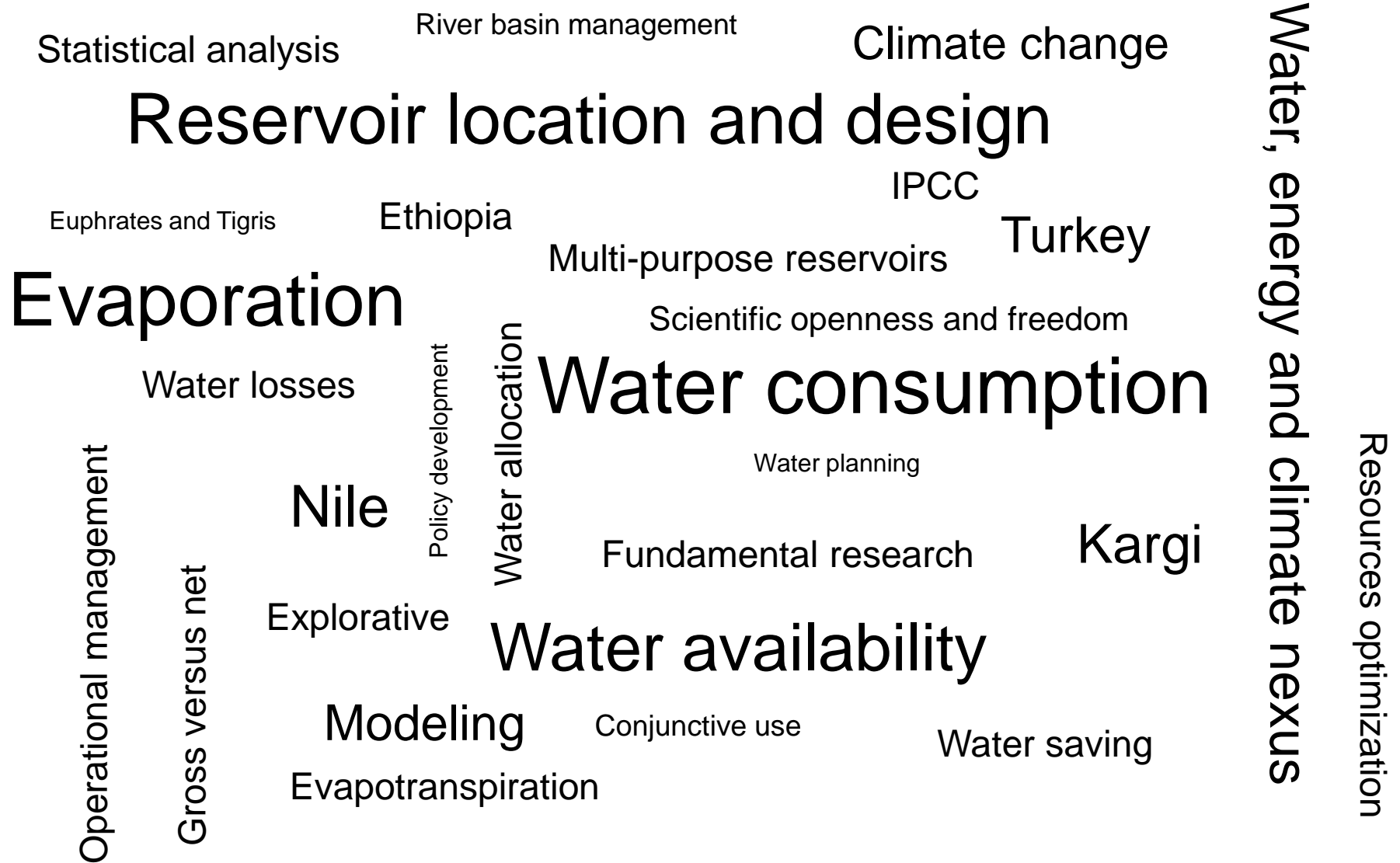
DIPLOMINGENIEUR  
(Dipl.-Ing.)

Betreuer: Bruno Giordano



# **‘The meat and the flesh’**

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



# Possible Case studies

