Integrated Water Management

Week 2:

Scenarios and Tools

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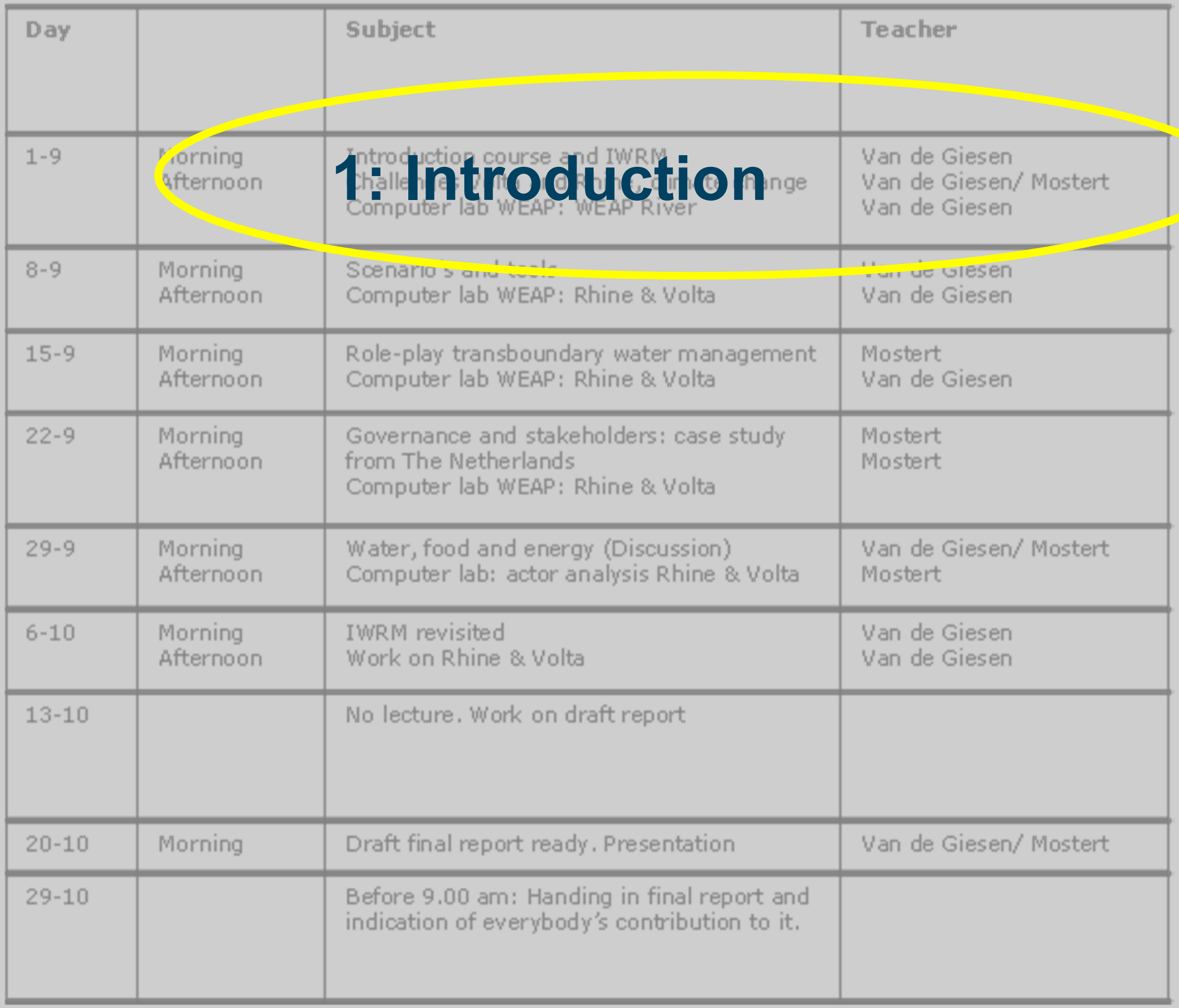
Water Management
Civil Engineering and Geosciences
Technical University Delft

IWM Fall 2013

Week 2: Scenarios & Tools

Course Outline

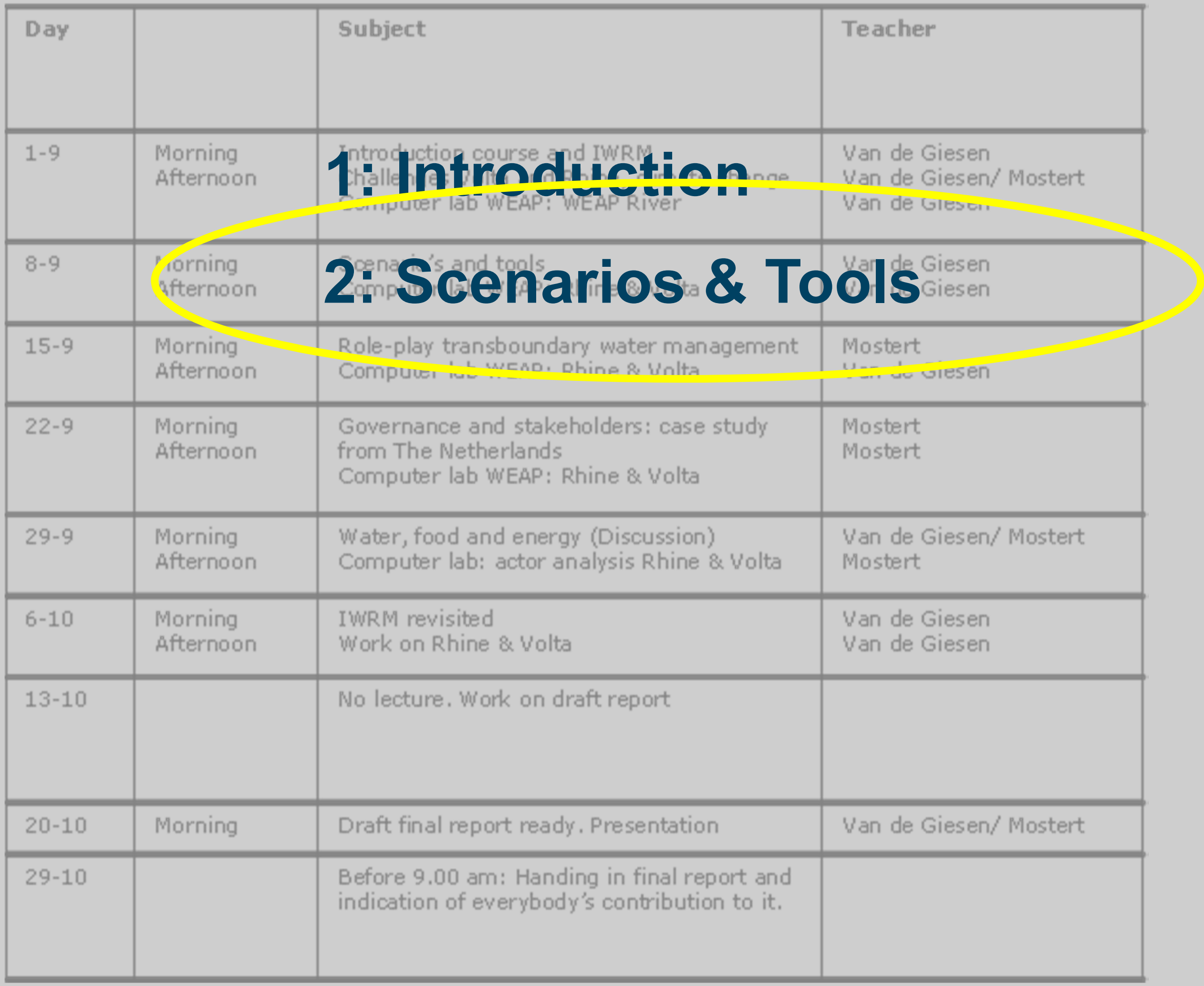


Day		Subject	Teacher
1-9	Morning Afternoon	Introduction course and IWRM Challenges Volta and Rhine: climate change Computer lab WEAP: WEAP River	Van de Giesen Van de Giesen/ Mostert Van de Giesen
8-9	Morning Afternoon	Scenario's and tools Computer lab WEAP: Rhine & Volta	Van de Giesen Van de Giesen
15-9	Morning Afternoon	Role-play transboundary water management Computer lab WEAP: Rhine & Volta	Mostert Van de Giesen
22-9	Morning Afternoon	Governance and stakeholders: case study from The Netherlands Computer lab WEAP: Rhine & Volta	Mostert Mostert
29-9	Morning Afternoon	Water, food and energy (Discussion) Computer lab: actor analysis Rhine & Volta	Van de Giesen/ Mostert Mostert
6-10	Morning Afternoon	IWRM revisited Work on Rhine & Volta	Van de Giesen Van de Giesen
13-10		No lecture. Work on draft report	
20-10	Morning	Draft final report ready. Presentation	Van de Giesen/ Mostert
29-10		Before 9.00 am: Handing in final report and indication of everybody's contribution to it.	

1: Introduction

Week 2: Scenarios & Tools

Course Outline



1: Introduction

2: Scenarios & Tools

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Outline

- **What do we want to achieve?**
- Strategies to deal with multiple futures
- Inputs: Climate (+population, economic growth, …)
- Sub-models:
  - Hydrology
  - Irrigation
  - Hydropower
  - Heat
- Data sources (Volta&Rhine)
- Graph Theory & WEAP

What do we want to do?

- Model for stakeholders => optimal decisions

Week 2: Scenarios & Tools

Source: au.video.yahoo.com

What do we want to do?

- Model for stakeholders => optimal decisions
- Objective function:
  - Nature / physics
  - Stakeholders

What do we want to do?

- Model for stakeholders => optimal decisions

- Objective function:
    - Nature / physics => Before cookie break
    - Stakeholders => After cookie break

What do we want to do: Scenarios

- Objective function
- External forcing / boundary conditions (=> week 4)
- Constraints / institutions

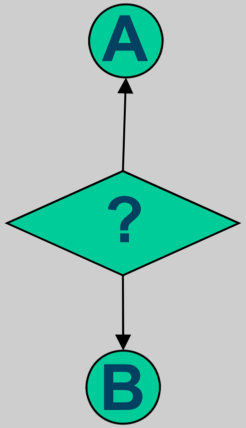
Week 2: Scenarios & Tools

What do we want to do: Scenarios

- Objective function
- External forcing / boundary conditions
- Constraints / institutions

Problem: Multiple futures!

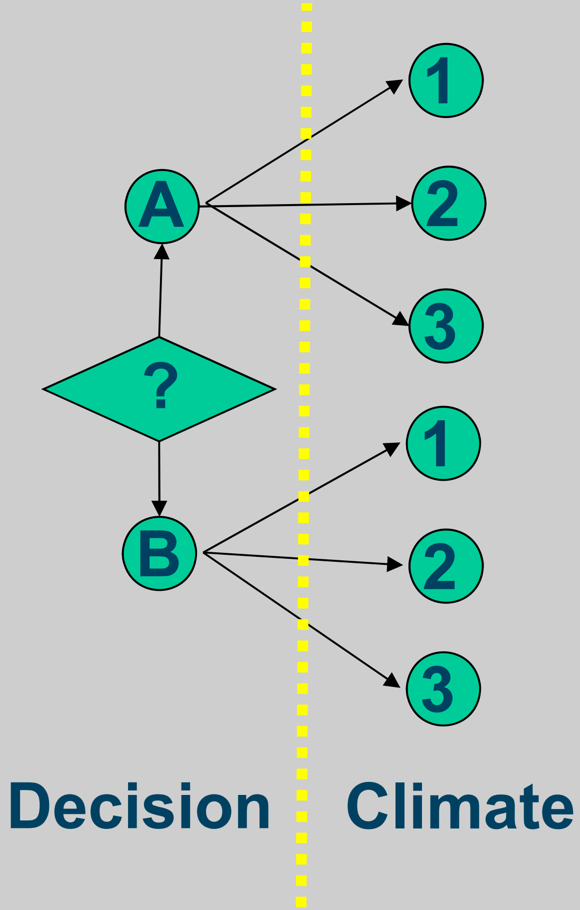
Multiple futures



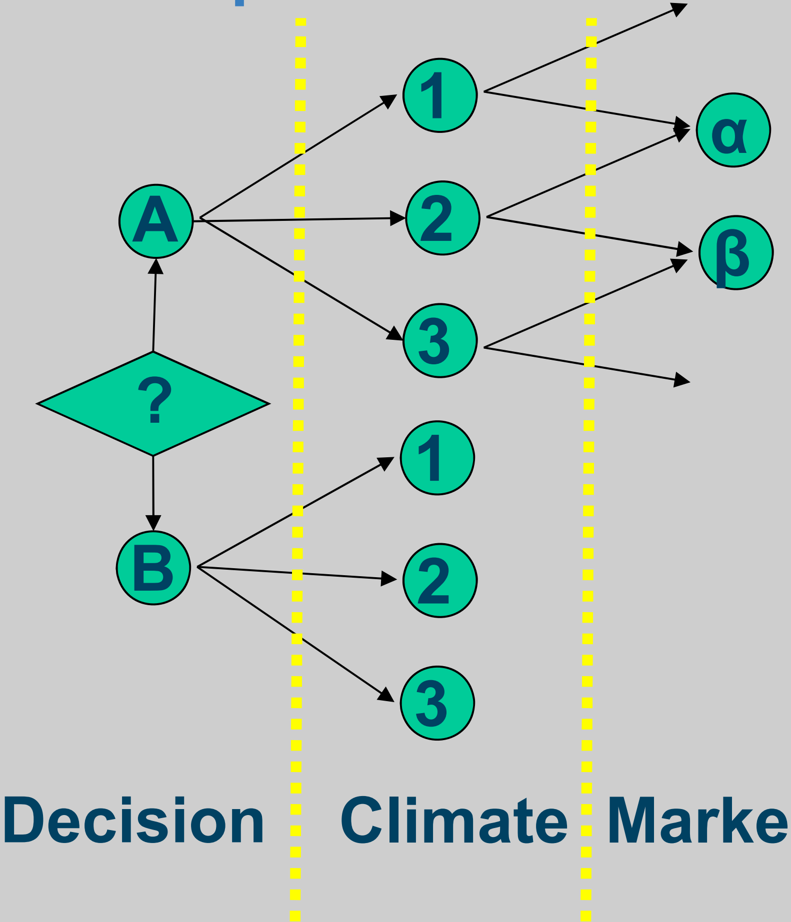
Decision

source: www.deondernemer.nl

Multiple futures

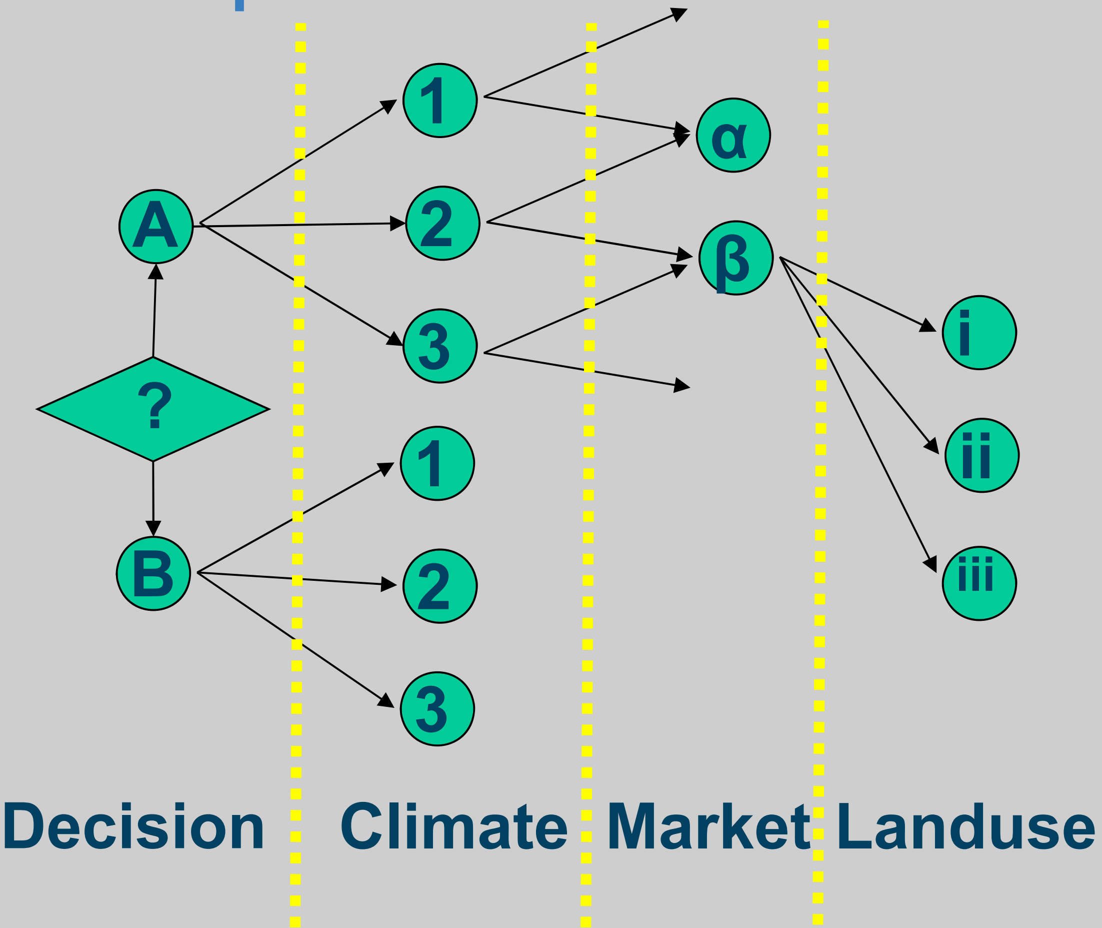


Multiple futures

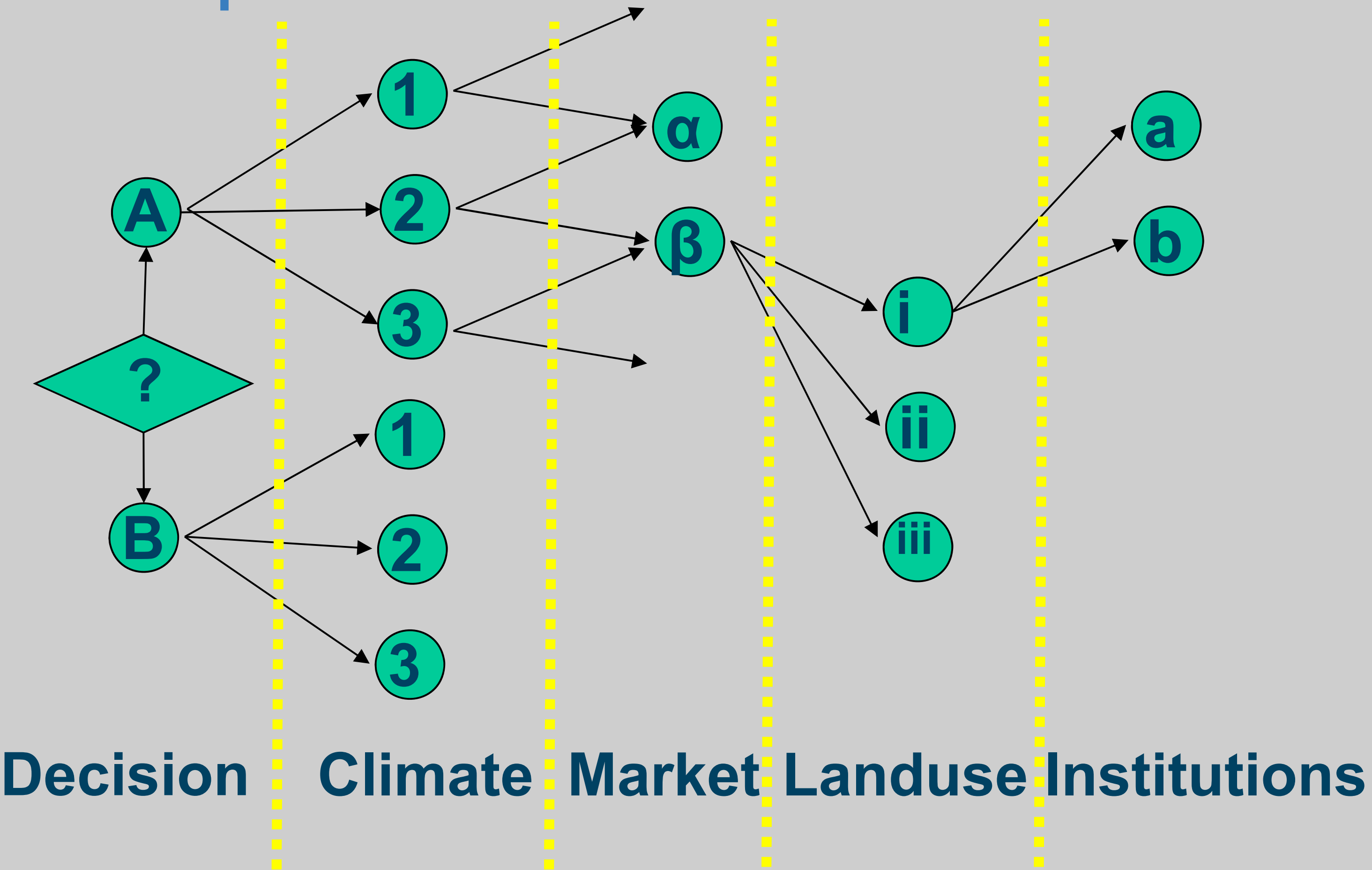


Decision Climate Market

Multiple futures



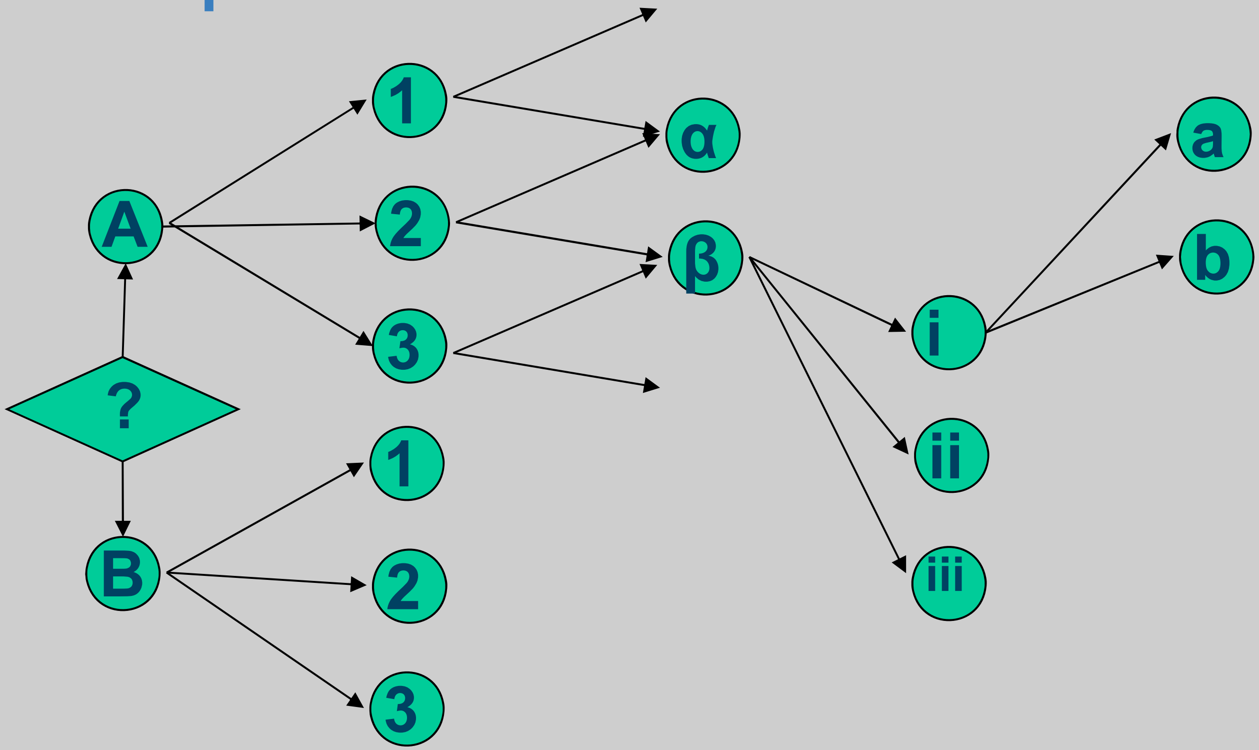
Multiple futures



Decision **Climate** **Market** **Landuse** **Institutions**

Week 2: Scenarios & Tools

Multiple futures



Decision **Climate** **Market** **Landuse** **Institutions**

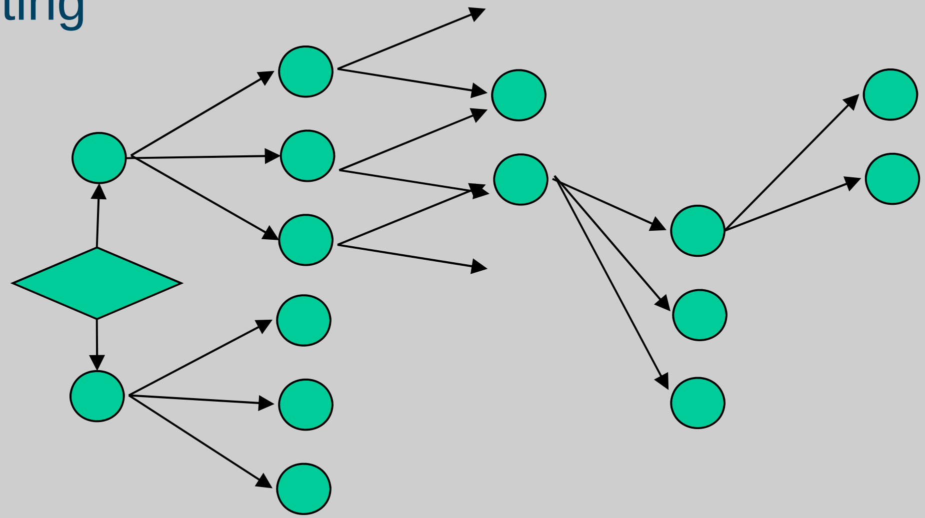
Futures=2x3x2x3x2x…

Multiple futures

- Strategies
  - Bayesian integration
  - Consistent story-lines (Hoekstra, IPCC)
  - Common future (Yates, Siemens)
  - …

Multiple futures

- Bayesian integration
  - Integrate along all pathways
  - Use priors to weigh decision points
  - Proper discounting
  - Robust design



Congli Dong

Multiple futures

- Story lines: IPCC scenarios
  - 40 emission scenarios
  - demography
  - economic development
  - technological development

Multiple futures

- Story lines: IPCC scenarios
  - A1: Globalization, rapid economic development
  - A2: Regional, low economic growth, high population
  - B1: Globalization, improved technologies
  - B2: Regional, medium economic growth, medium population

- Emissions, climate change, GCMs

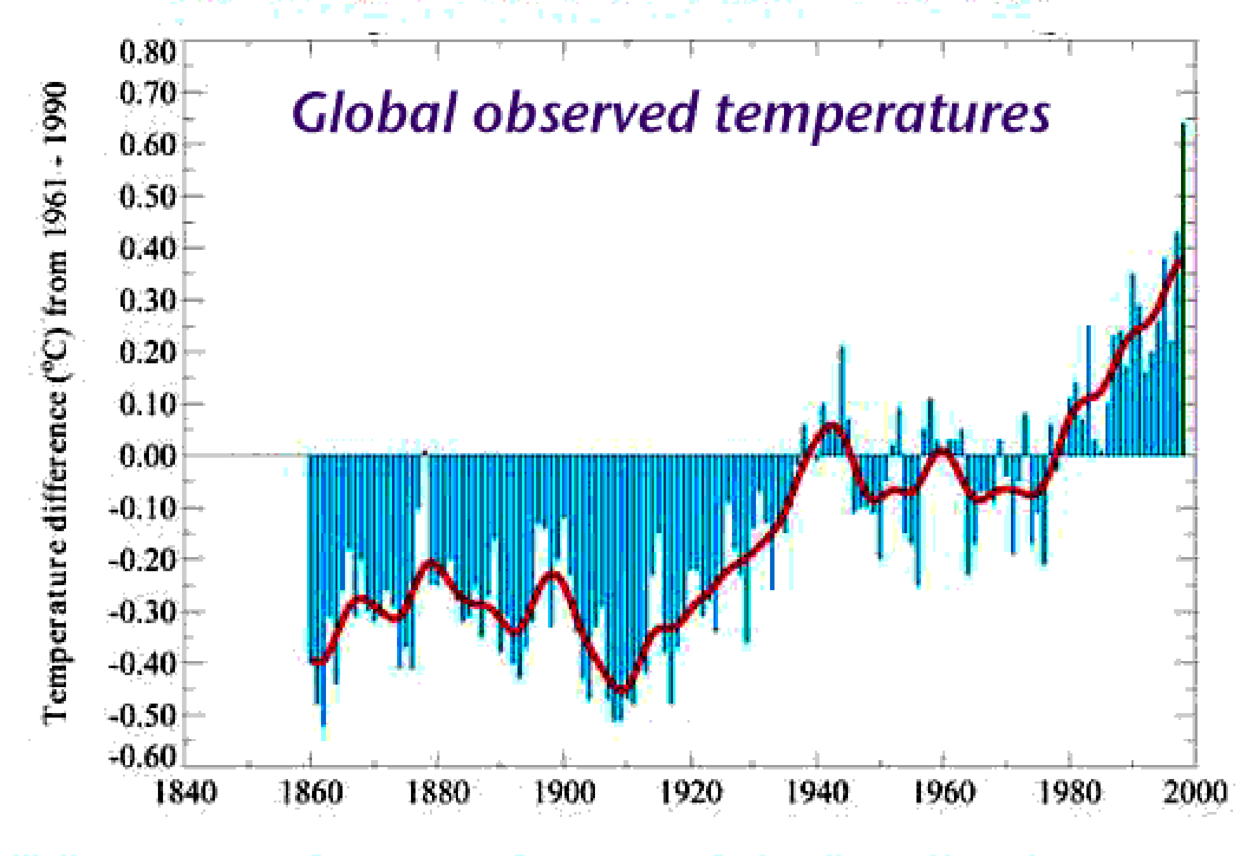
Multiple futures

- Common future
  - Especially good for stakeholders
  - Panel / forum
  - Subjectivity / perceptions

Multiple futures: IPCC story lines

- Climate scenarios
    - General Circulation Models (GCM’s)
    - GCM’s & water
    - Downscaling GCM’s

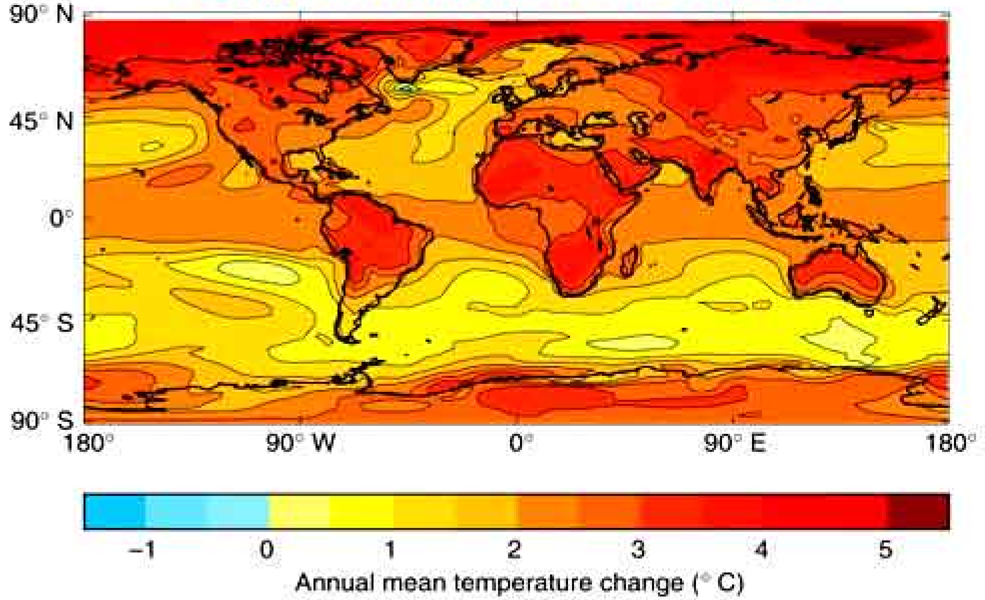
GCM's & Climate Change Scenarios



`source: www.inforse.org`

GCM's & Climate Change Scenarios

Figure 11: Projected Changes in Annual Temperatures for the 2050s



The projected change in annual temperatures for the 2050s compared with the present day, when the climate model is driven with an increase in greenhouse gas concentrations equivalent to about a 1% increase per year in CO_2

The Met Office. Hadley Centre for Climate Prediction and Research.

GCM's & Climate Change Scenarios

REPORTS

Global Water Resources: Vulnerability from Climate Change and Population Growth

Charles J. Vörösmarty,[1,2,4,3*] Pamela Green,[1,3,4] Joseph Salisbury,[1,3,4] Richard B. Lammers[1,2,4]

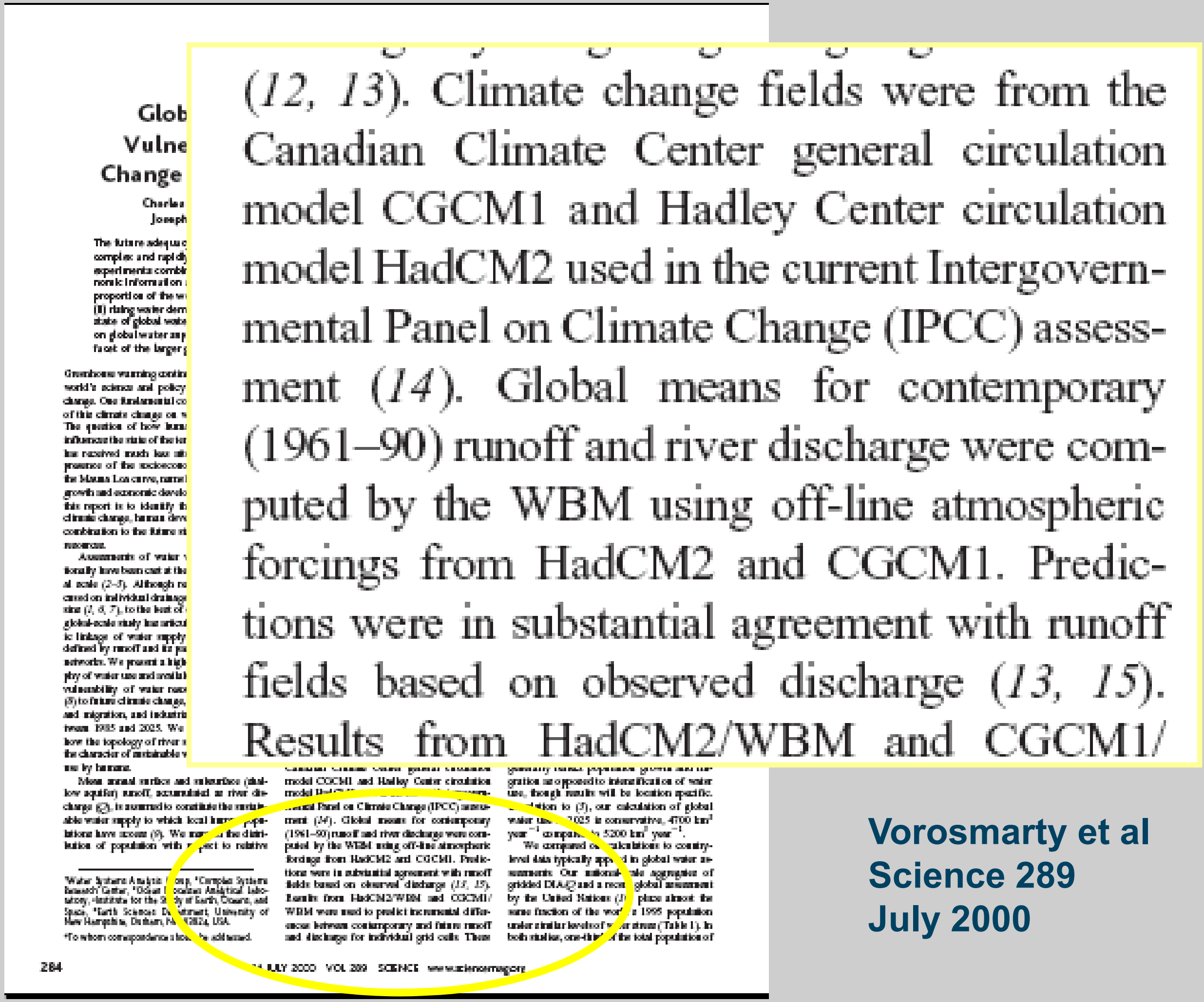
The future adequacy of freshwater resources is difficult to assess, owing to a complex and rapidly changing geography of water supply and use. Numerical experiments combining climate model outputs, water budgets, and socioeconomic information along digitized river networks demonstrate that (i) a large proportion of the world's population is currently experiencing water stress and (ii) rising water demands greatly outweigh greenhouse warming in defining the state of global water systems to 2025. Consideration of direct human impacts on global water supply remains a poorly articulated but potentially important facet of the larger global change question.

284 14 JULY 2000 VOL 289 SCIENCE www.sciencemag.org

Global Water Resources: Vulnerability from Climate Change and Population Growth

Vorosmarty et al
Science 289
July 2000

GCM's & Climate Change Scenarios



(*12, 13*). Climate change fields were from the Canadian Climate Center general circulation model CGCM1 and Hadley Center circulation model HadCM2 used in the current Intergovernmental Panel on Climate Change (IPCC) assessment (*14*). Global means for contemporary (1961–90) runoff and river discharge were computed by the WBM using off-line atmospheric forcings from HadCM2 and CGCM1. Predictions were in substantial agreement with runoff fields based on observed discharge (*13, 15*). Results from HadCM2/WBM and CGCM1/

Vorosmarty et al
Science 289
July 2000

GCM's & Climate Change Scenarios

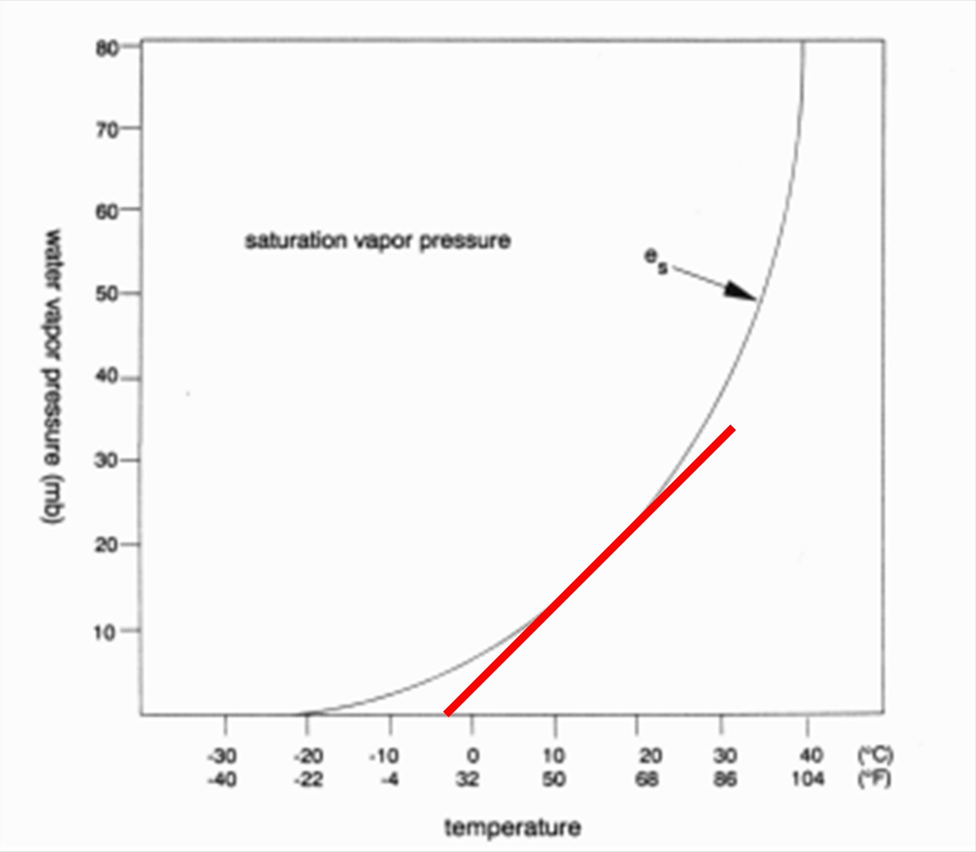
Clausius-Clapeyron

$$\frac{d \ln p}{d\,T} = \frac{\Delta H_{vap}}{RT^2}$$

+1°C $\Rightarrow$ +7% H_2O

Probably:

+1°C $\Rightarrow$ +2-4% H_2O



GCM's & Climate Change Scenarios

Clausius-Clapeyron

$$\frac{\mathrm{d}\ln p}{\mathrm{d}T} = \frac{\Delta H_{vap}}{RT^2}$$

+1°C ⇒ +7% H_2O

Probably:

+1°C ⇒ +2-4% H_2O

or **7%???**

Science

13 July 2007 | $10

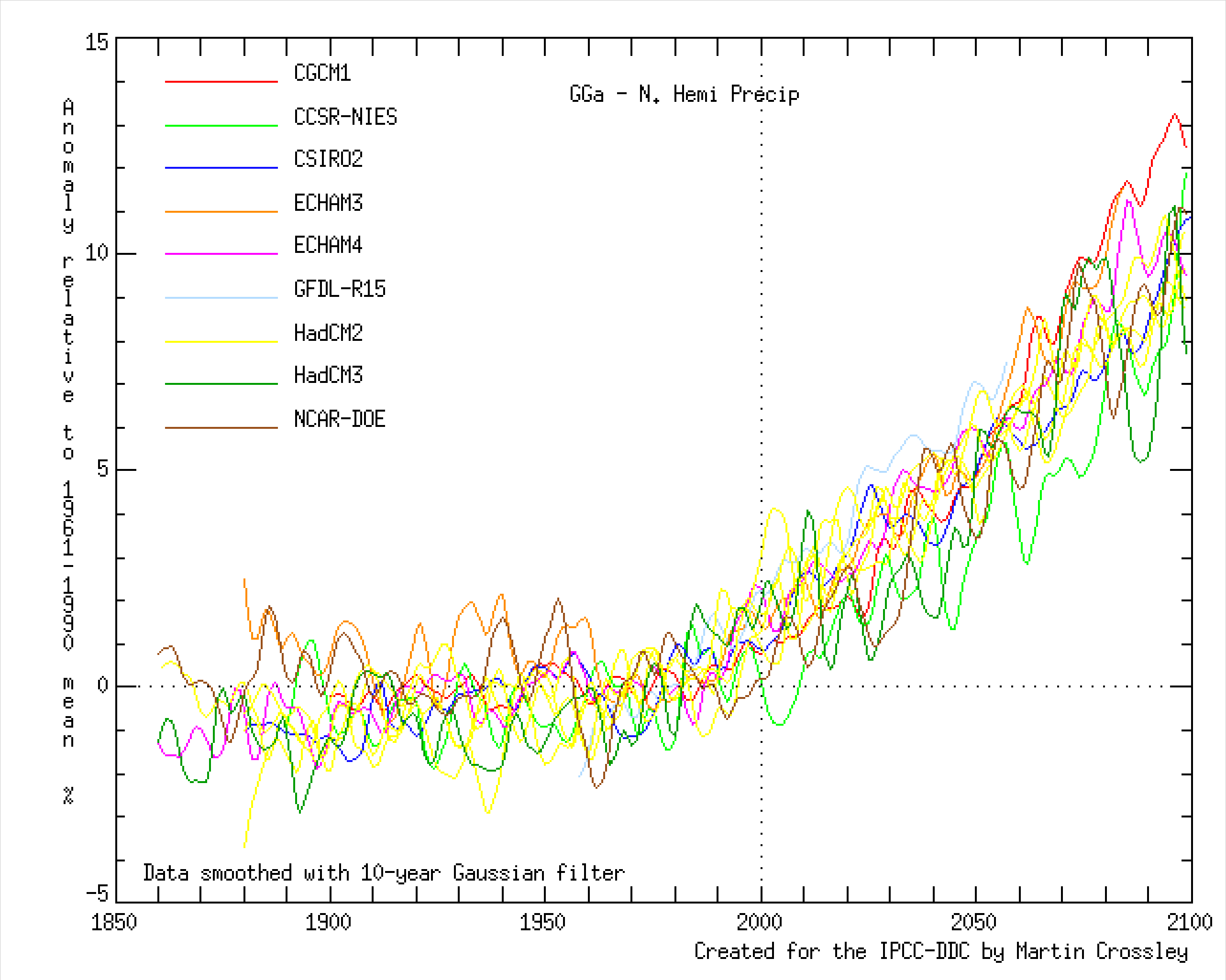
How Much More Rain Will Global Warming Bring?

Frank J. Wentz,* Lucrezia Ricciardulli, Kyle Hilburn, Carl Mears

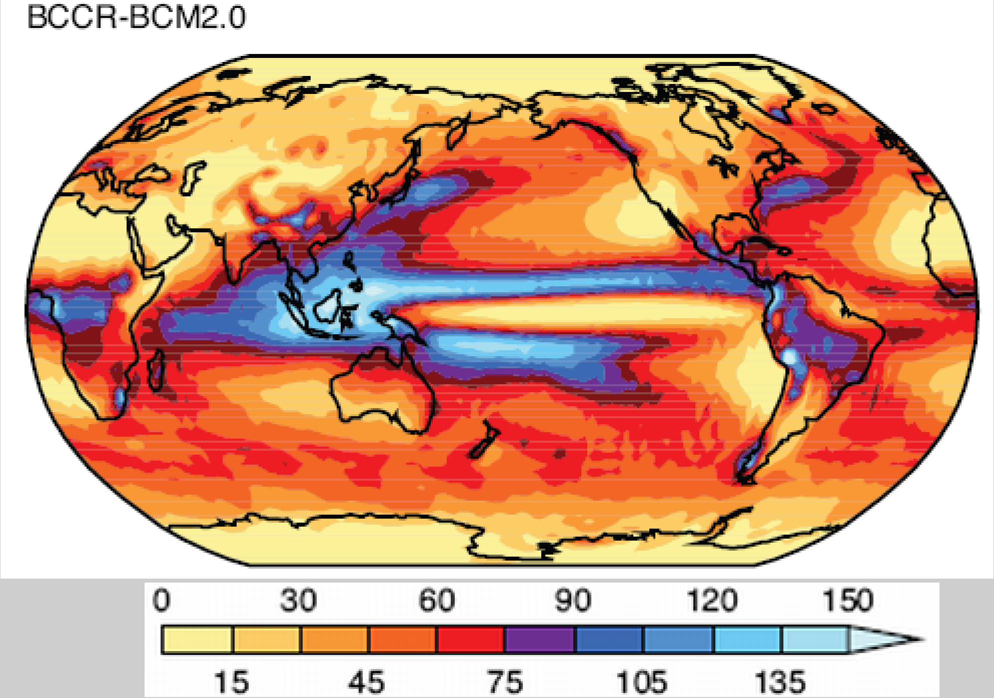
AAAS

Science 289 July 2007

GCM’s & Climate Change Scenarios



GCM’s & Climate Change Scenarios

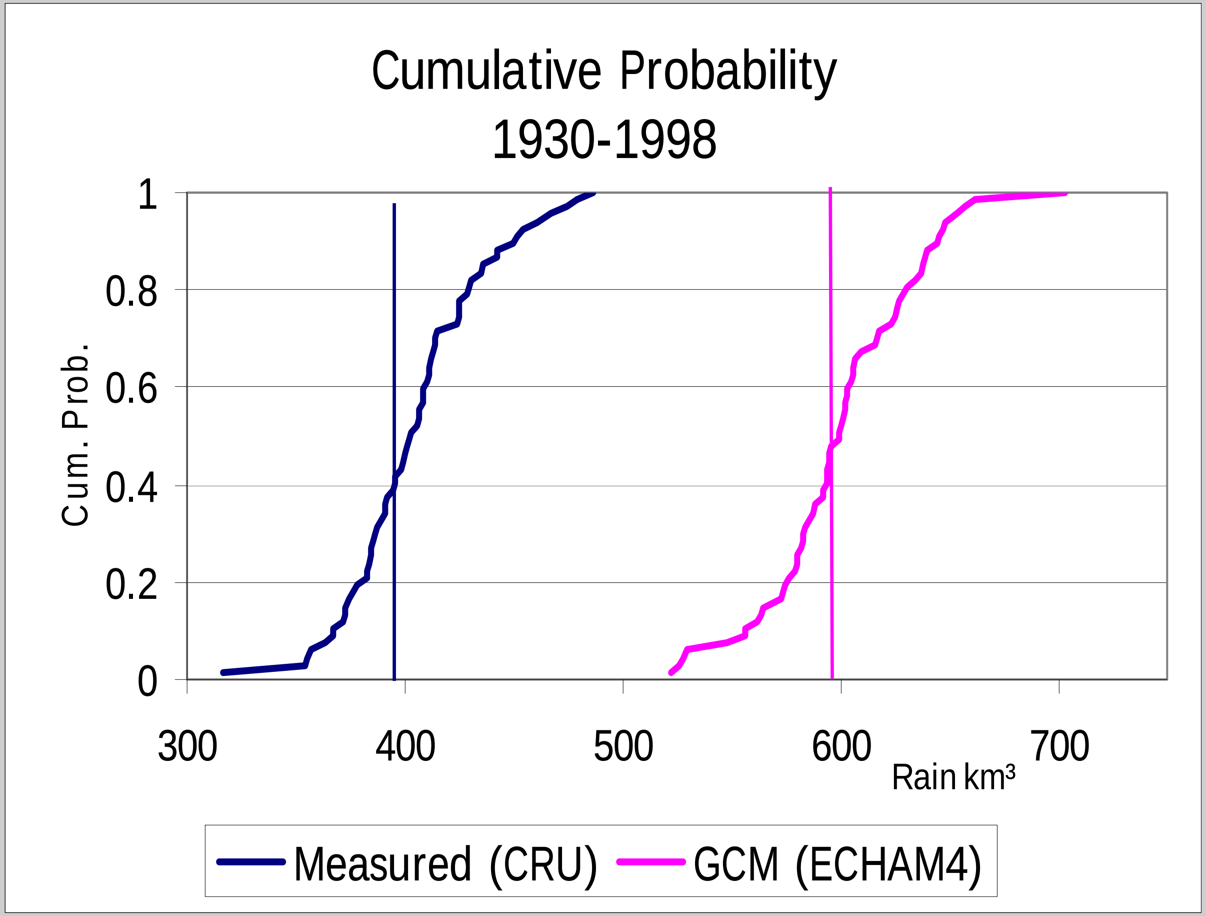


Error rainfall (cm)

Downscaling GCM’s

- GCM’s are not good for water
- GCM’s are not good locally
- Strategies
  - KNMI
  - WaterGAP
  - Example Volta

Downscaling GCM's



Volta Basin

Downscaling GCM's

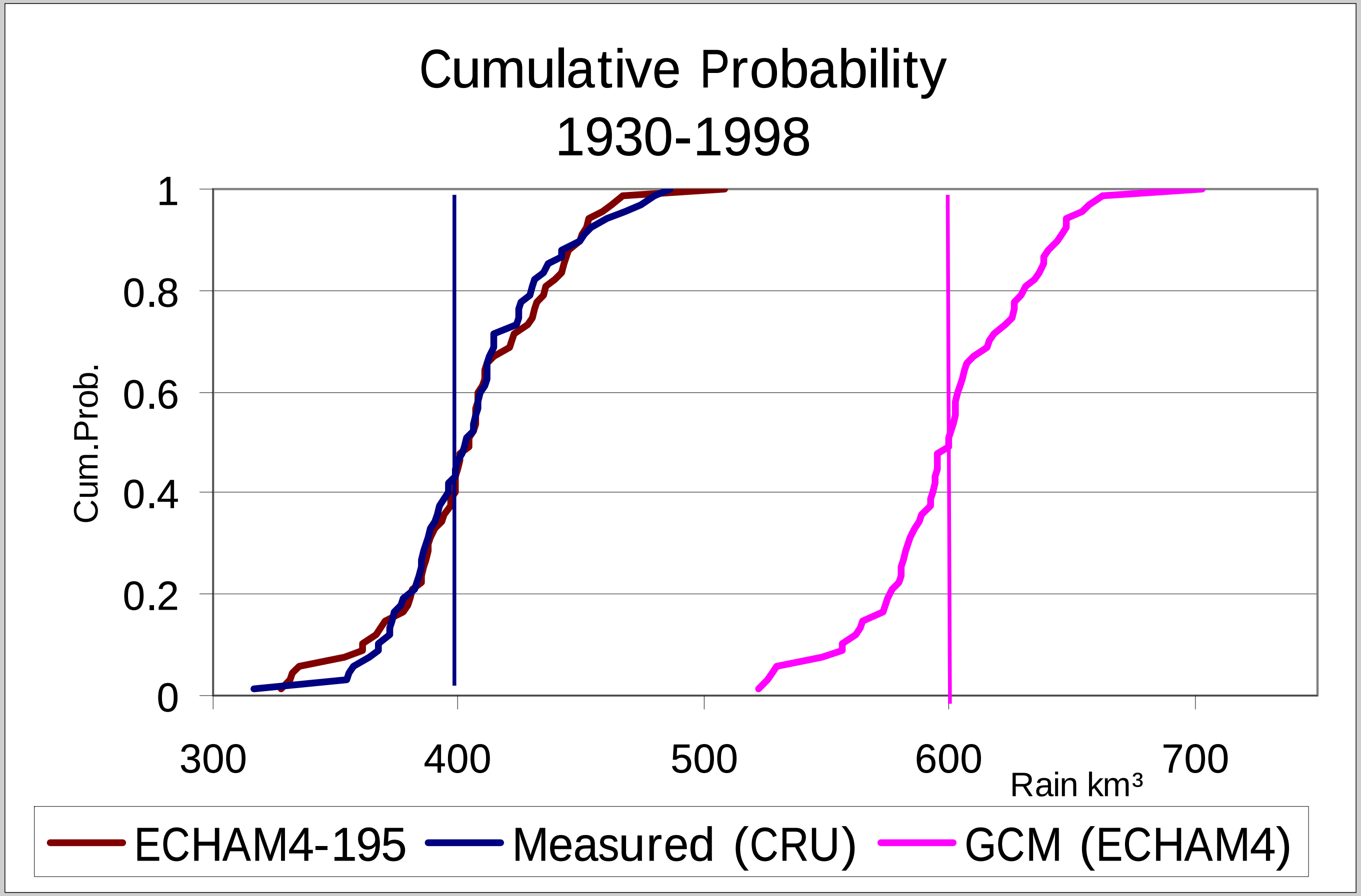
- Strategies

$$\overset{\frown}{p}_1 \propto \mu_1 + \sigma_1 \overset{\frown}{\chi}$$

$$\overset{\frown}{p}_2 \propto \mu_2 + \sigma_2 \overset{\frown}{\chi}$$

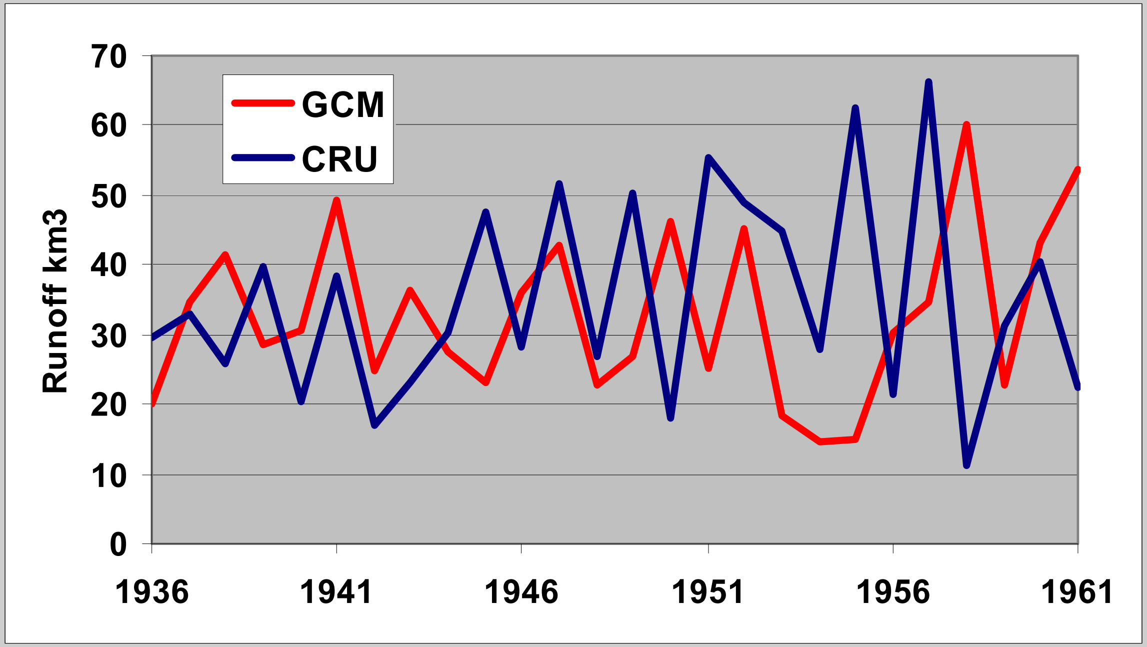
$$\overset{\frown}{p}_2 \propto \mu_2 + \sigma_2 \frac{\overset{\frown}{p}_1 - \mu_1}{\sigma_1}$$

Comparison Historical and GCM Rainfall, ECHAM4



Normalization: Subtract/Add Mean

Comparison GCM (ECHAM4) and Historical Runoff

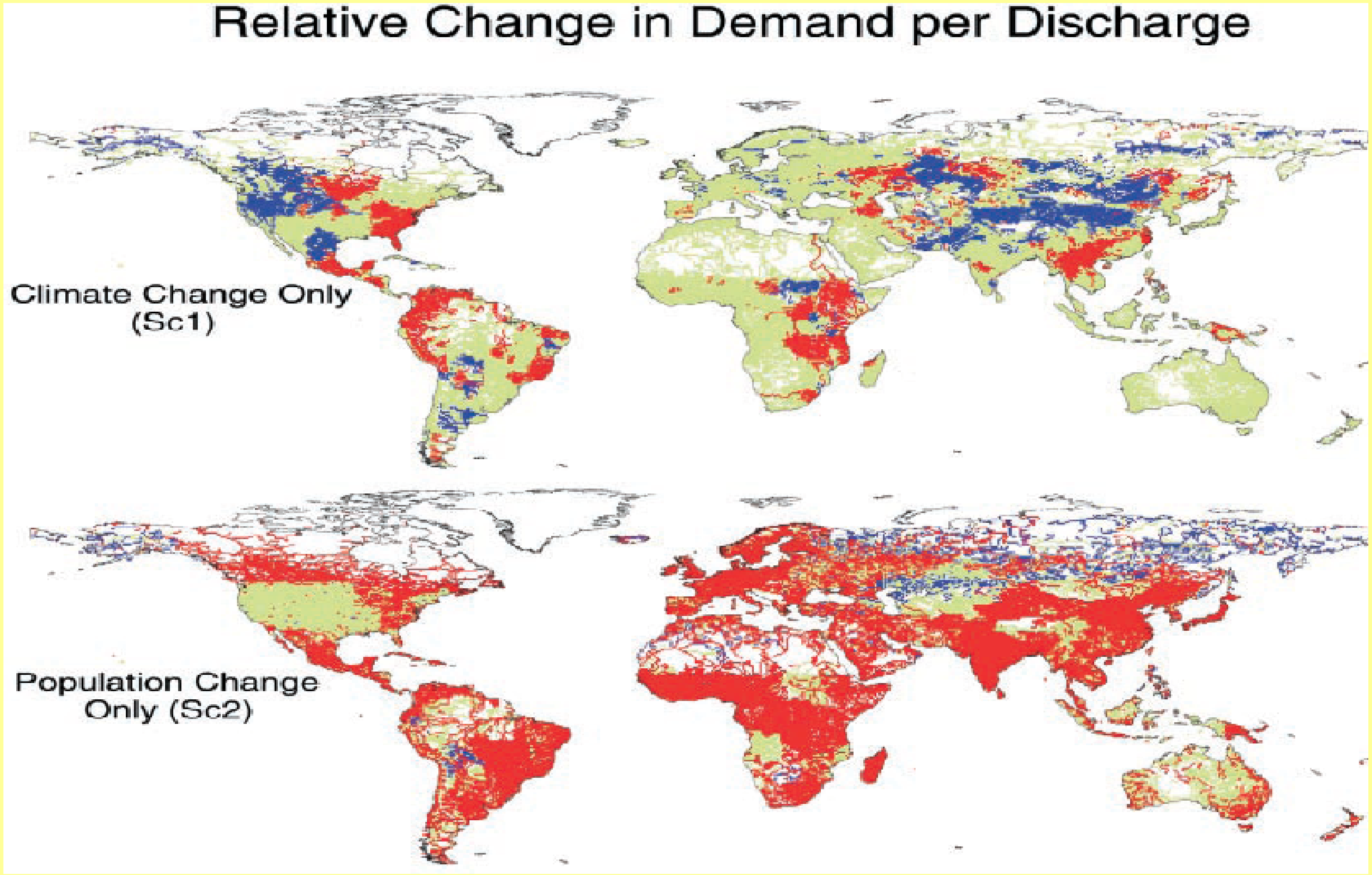


Normalization: Average Monthly Difference

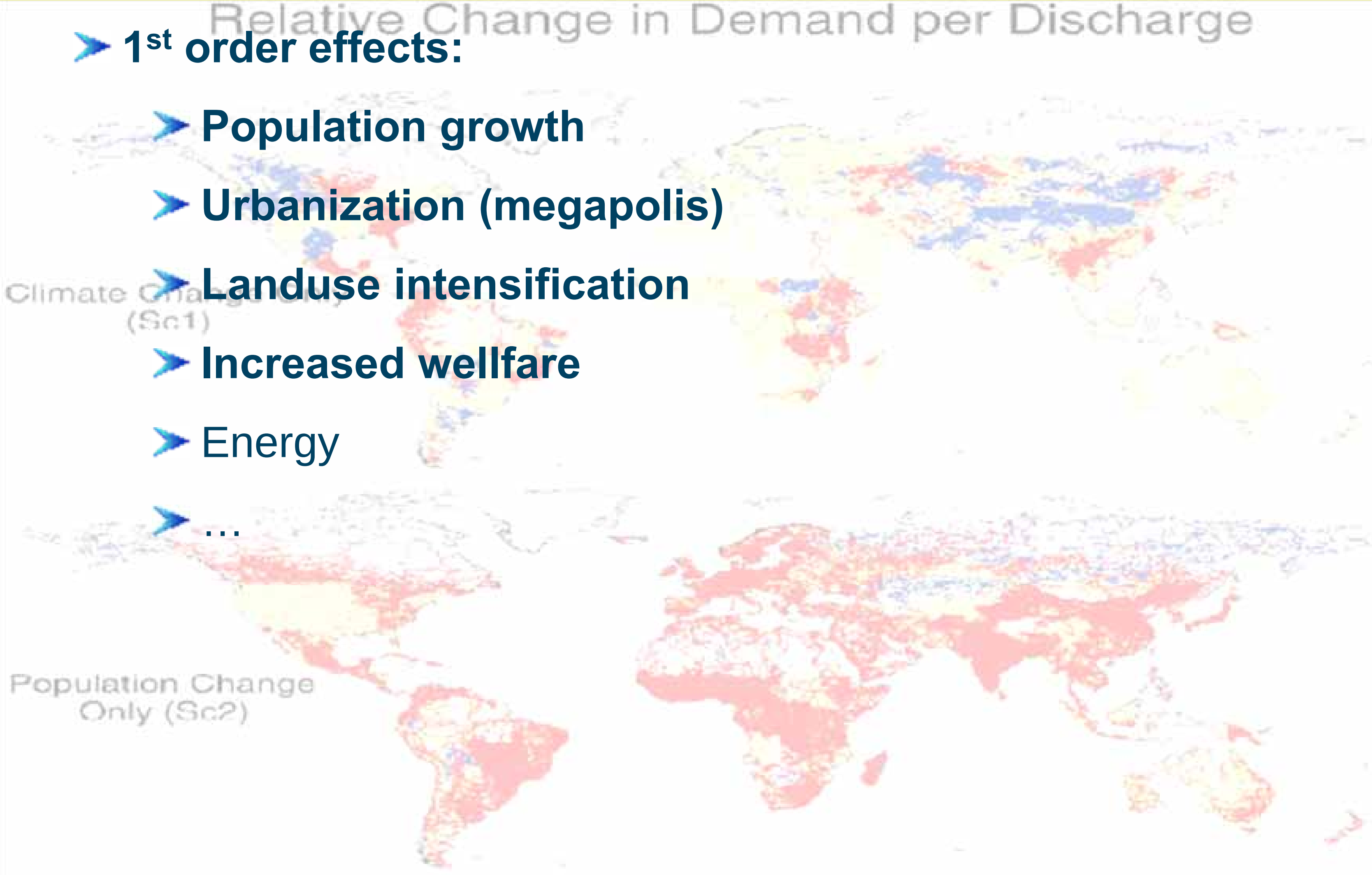
Average OK (33 km³ vs 36 km³)

SD OK (12 km³ vs 14 km³)

Climate uncertainty vs 1st order effects

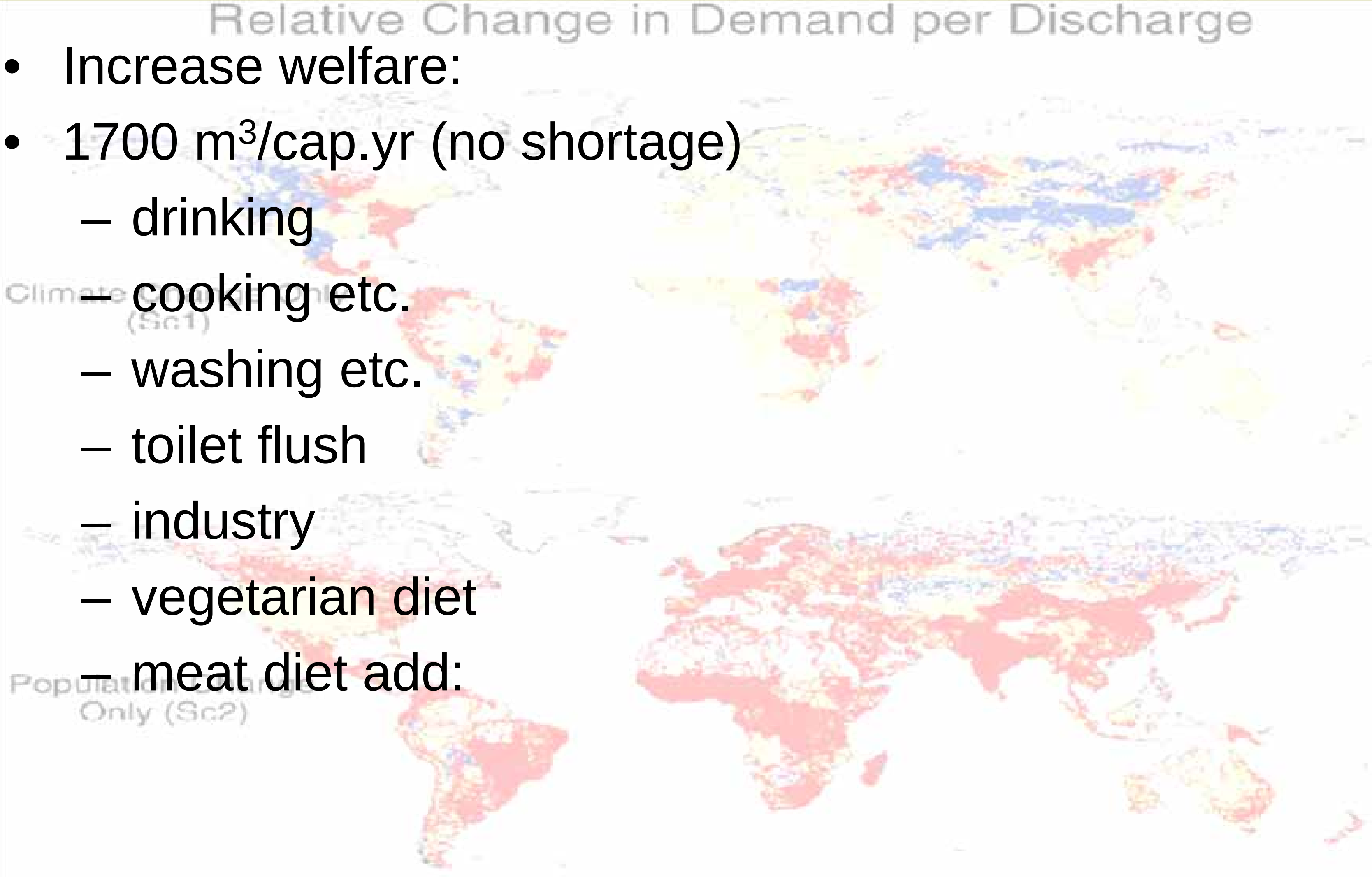


Climate uncertainty vs 1st order effects



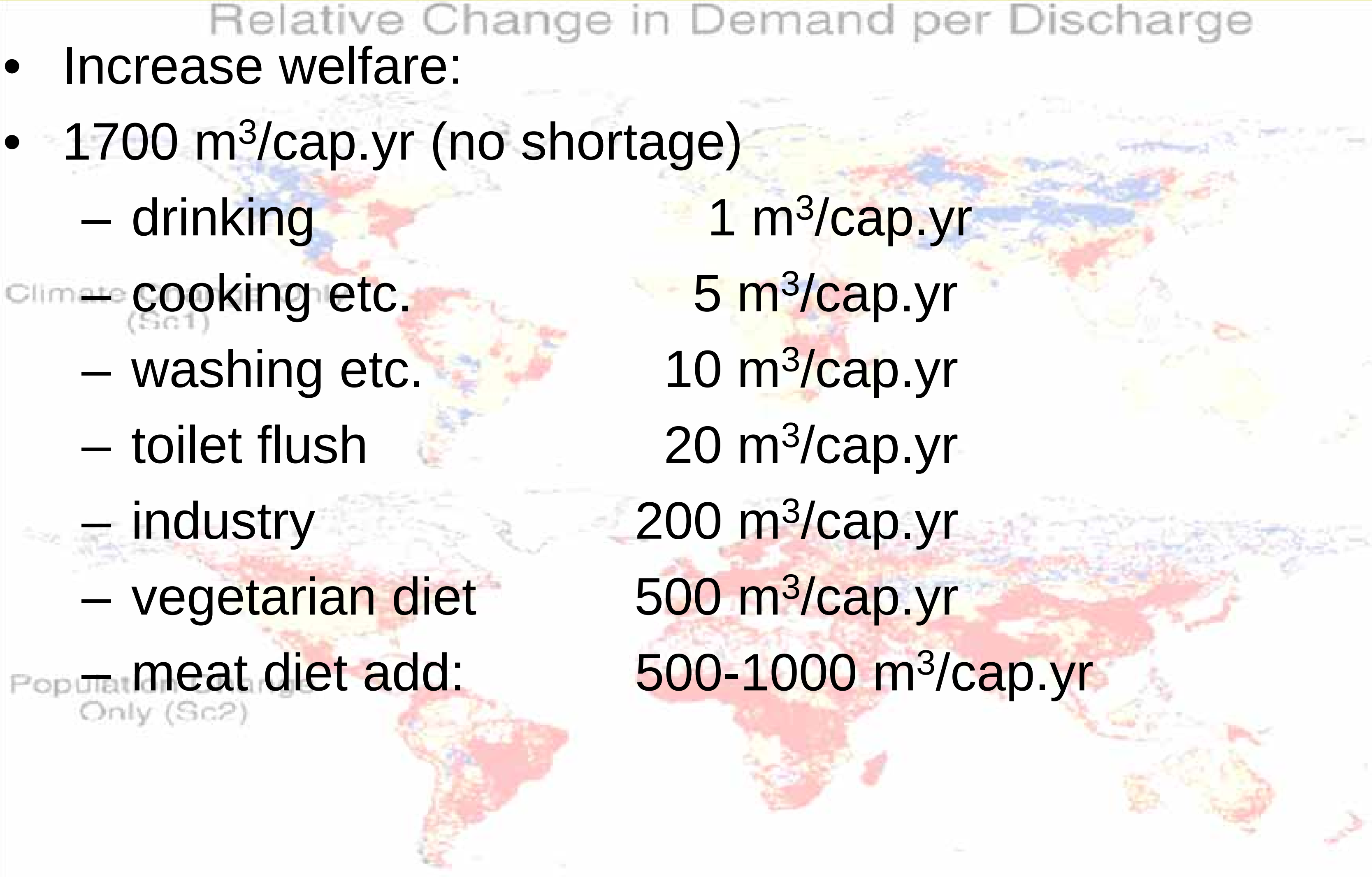
- **1st order effects:**
  - **Population growth**
  - **Urbanization (megapolis)**
  - **Landuse intensification**
  - **Increased wellfare**
  - Energy
  - …

Climate uncertainty vs 1st order effects



- Increase welfare:
- 1700 m^3/cap.yr (no shortage)
  - drinking
  - cooking etc.
  - washing etc.
  - toilet flush
  - industry
  - vegetarian diet
  - meat diet add:

Climate uncertainty vs 1st order effects



- Increase welfare:
- 1700 m^3/cap.yr (no shortage)

– drinking	1 m^3/cap.yr
– cooking etc.	5 m^3/cap.yr
– washing etc.	10 m^3/cap.yr
– toilet flush	20 m^3/cap.yr
– industry	200 m^3/cap.yr
– vegetarian diet	500 m^3/cap.yr
– meat diet add:	500-1000 m^3/cap.yr

Sub-models

- Hydrology
- Water use:
  - Household
  - (Industry)
  - Irrigation
  - Hydropower
  - Ecology/temperature

Hydrology:

Link between climate and management

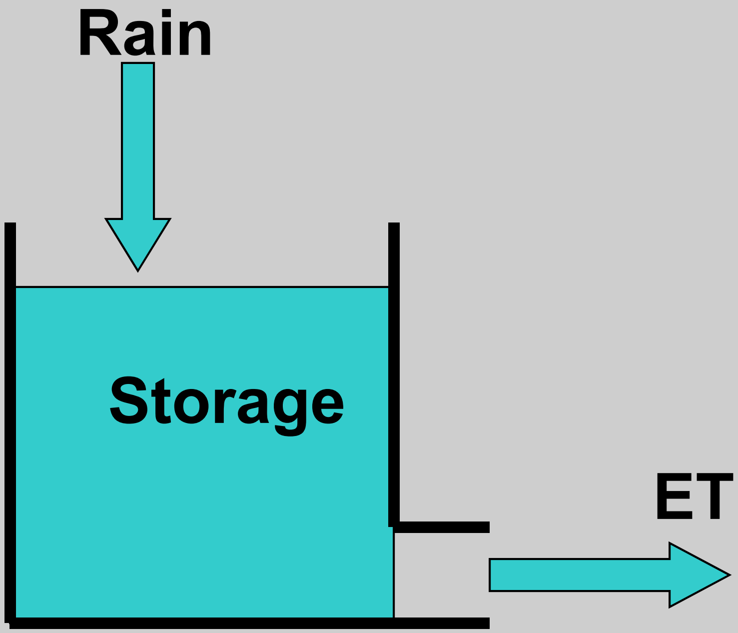
- Rainfall – runoff models
    - Volta
    - Rhine
    - Bootstrap runoff records

Hydrology: Data sources

- GRDC: http://grdc.bafg.de
- CRU: http://www.cru.uea.ac.uk
- GCM's: http://cera-www.dkrz.de/IPCC_DDC/
  - Volta: GLOWA Volta CD
  - Rhine: http://www.iksr.de

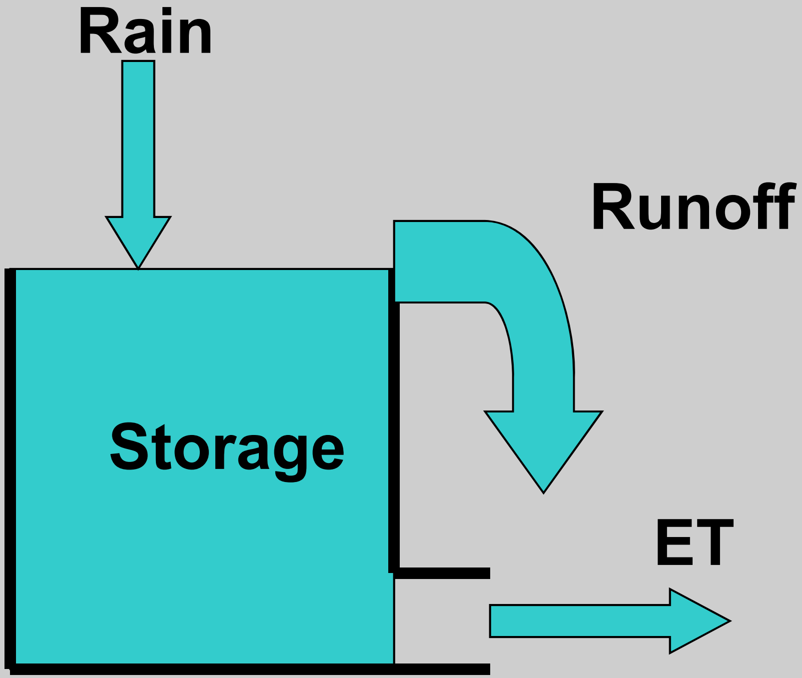
Simple hydrological models

Volta



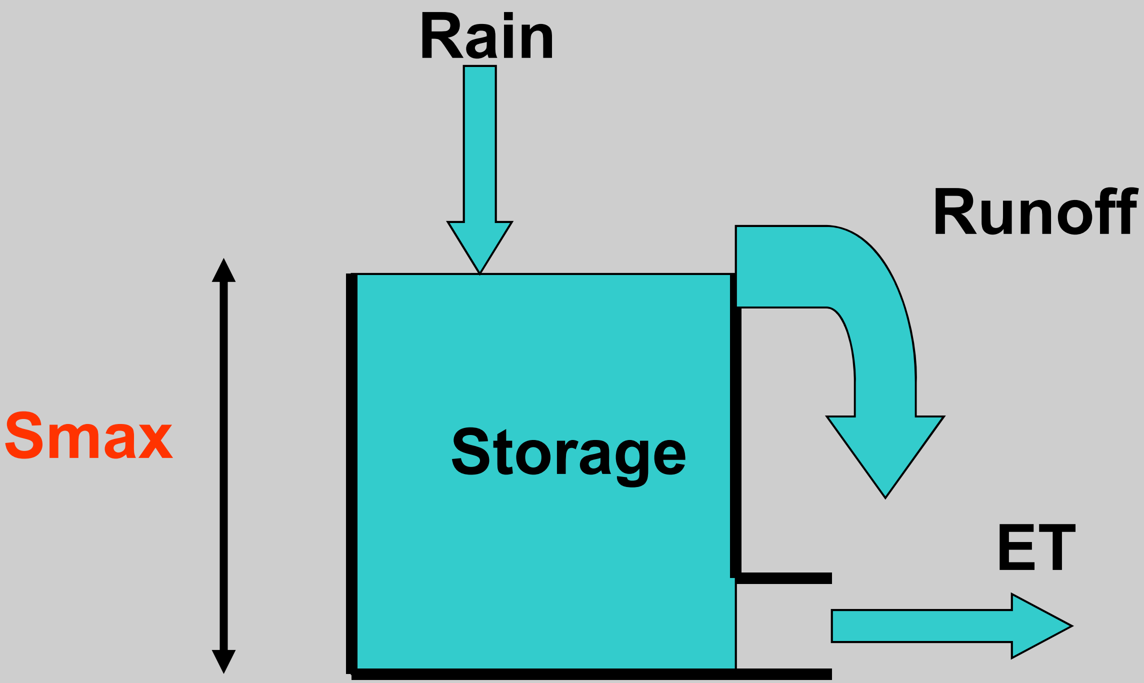
Simple hydrological models

Volta



Simple hydrological models

Volta



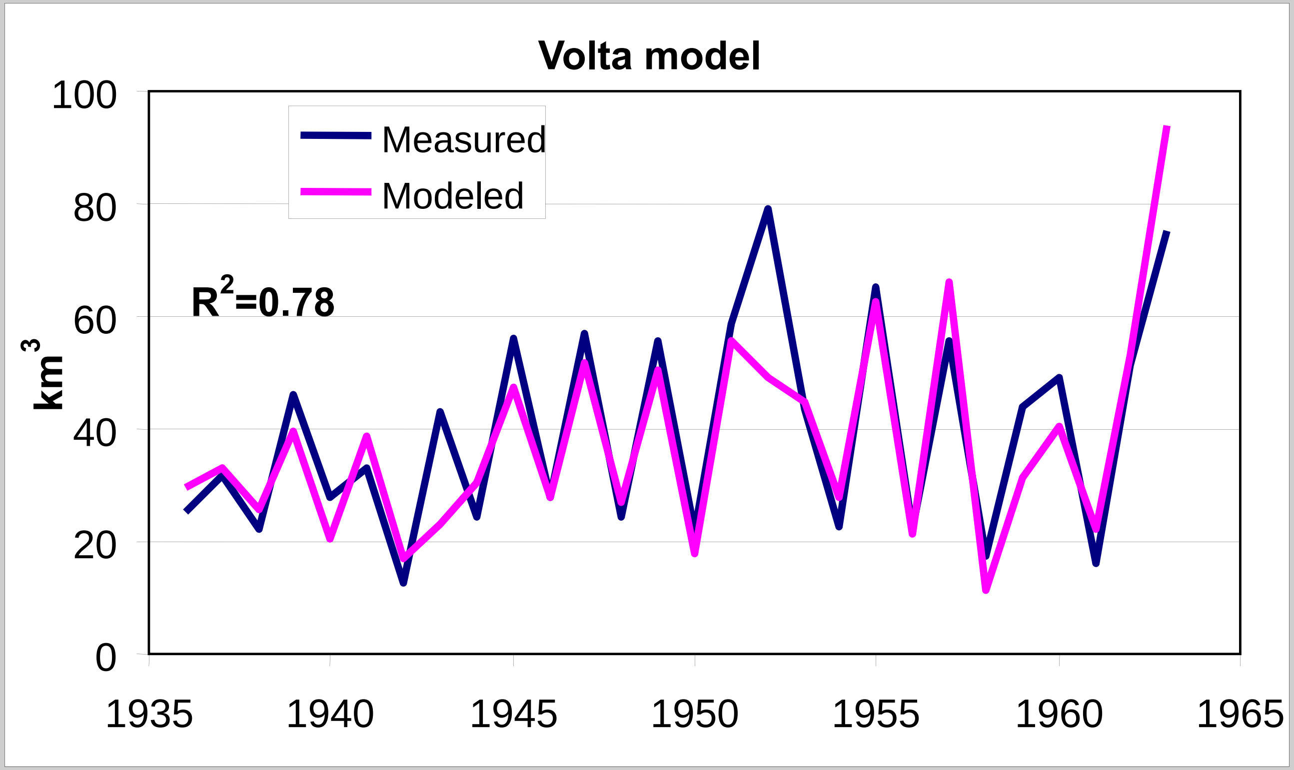
Simple hydrological models

Volta

Bucket model

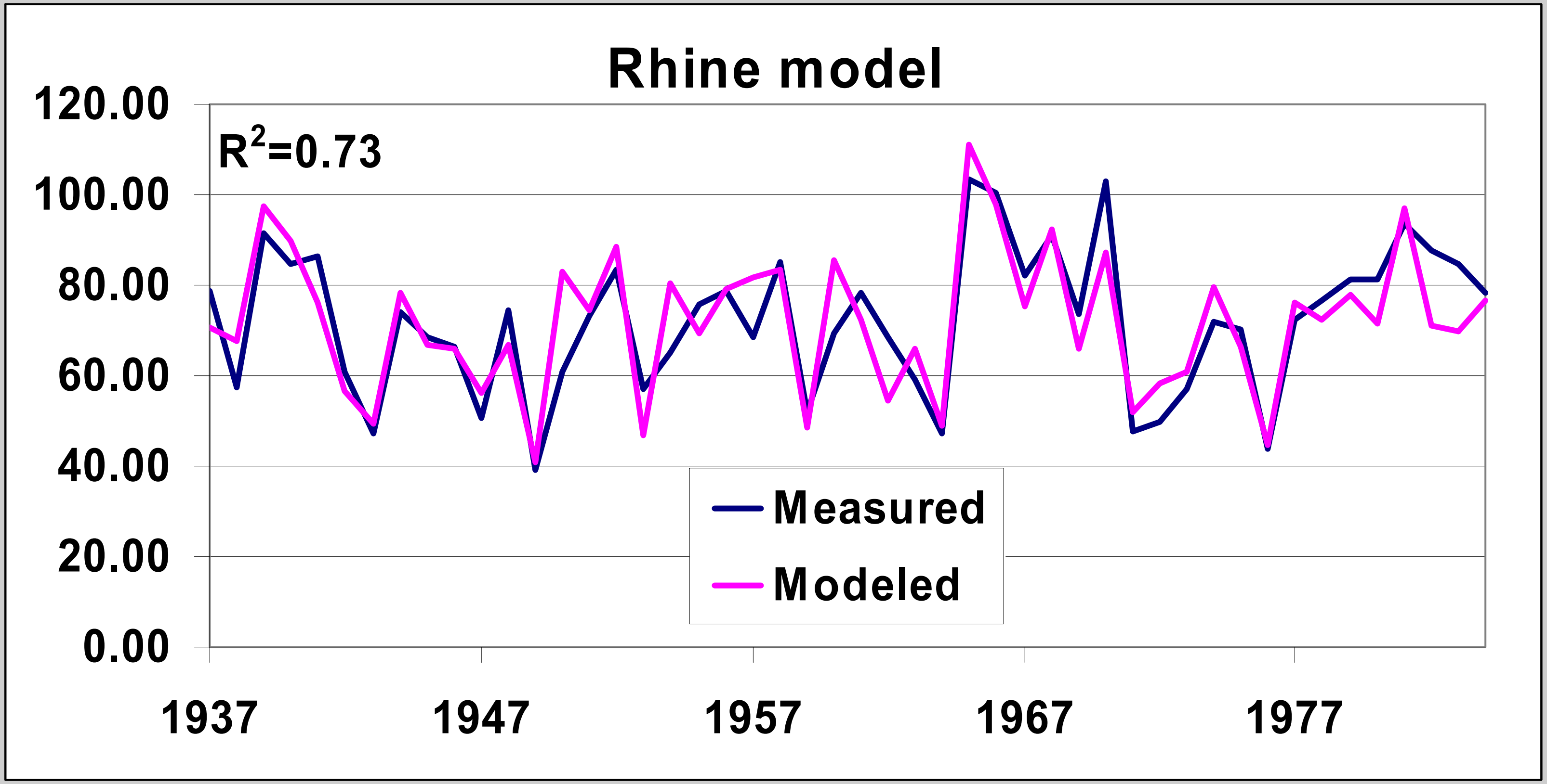
1. $S'_n = S_{n-1} + P_n$
2. $Q_n = \max(S'_n - S_{max}, 0)$
3. $S''_n = S'_n - Q$
4. $E = E_{pot} * (S''_n / S_{max})$
5. $S_n = S''_n - E$

Simple hydrological models



Bucket model

Simple hydrological models



Bucket model

Simple hydrological models

Rhine - alternative

Bucket model
- Good for water limited evaporation
- Reaction within time step

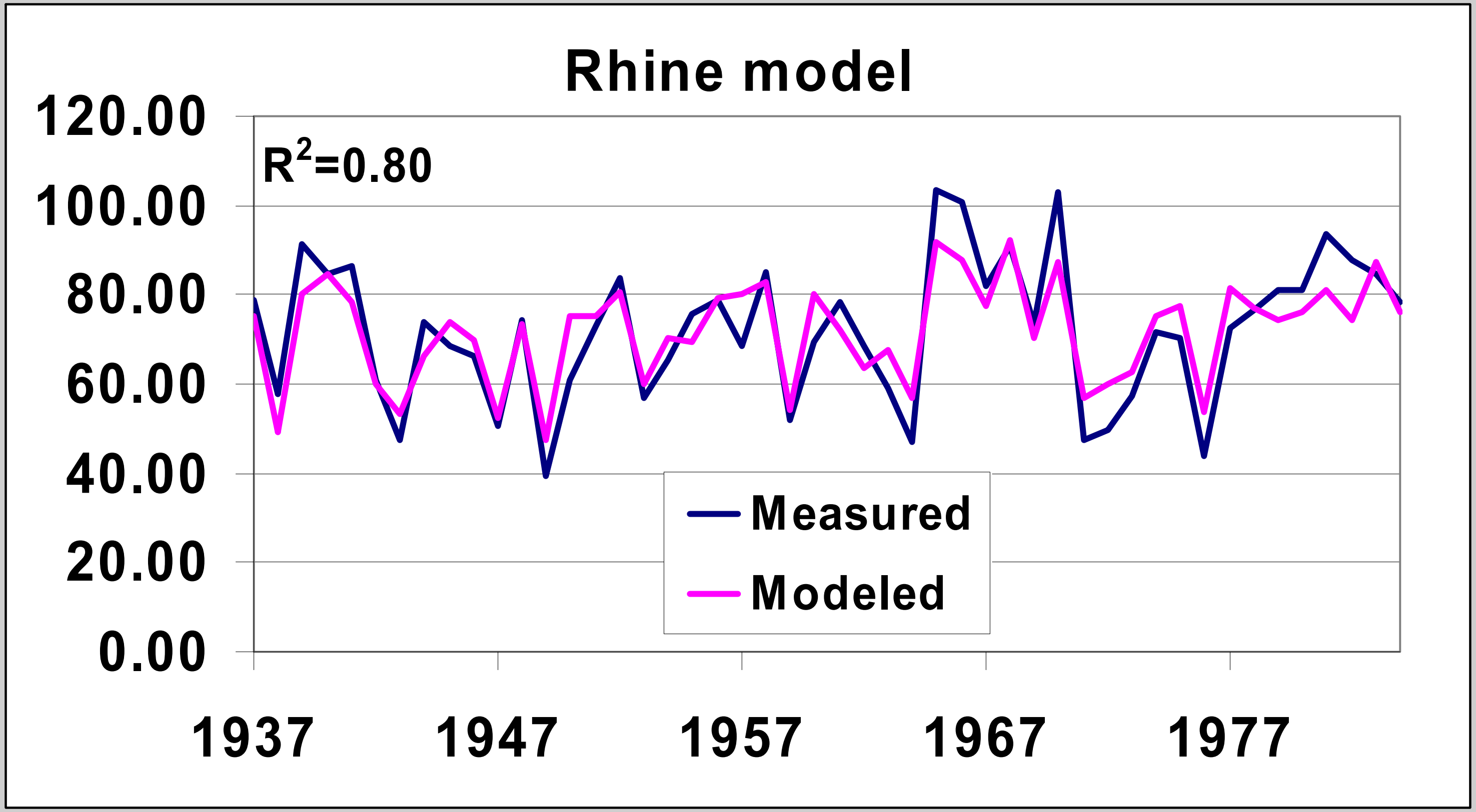
Simple hydrological models

Rhine - alternative

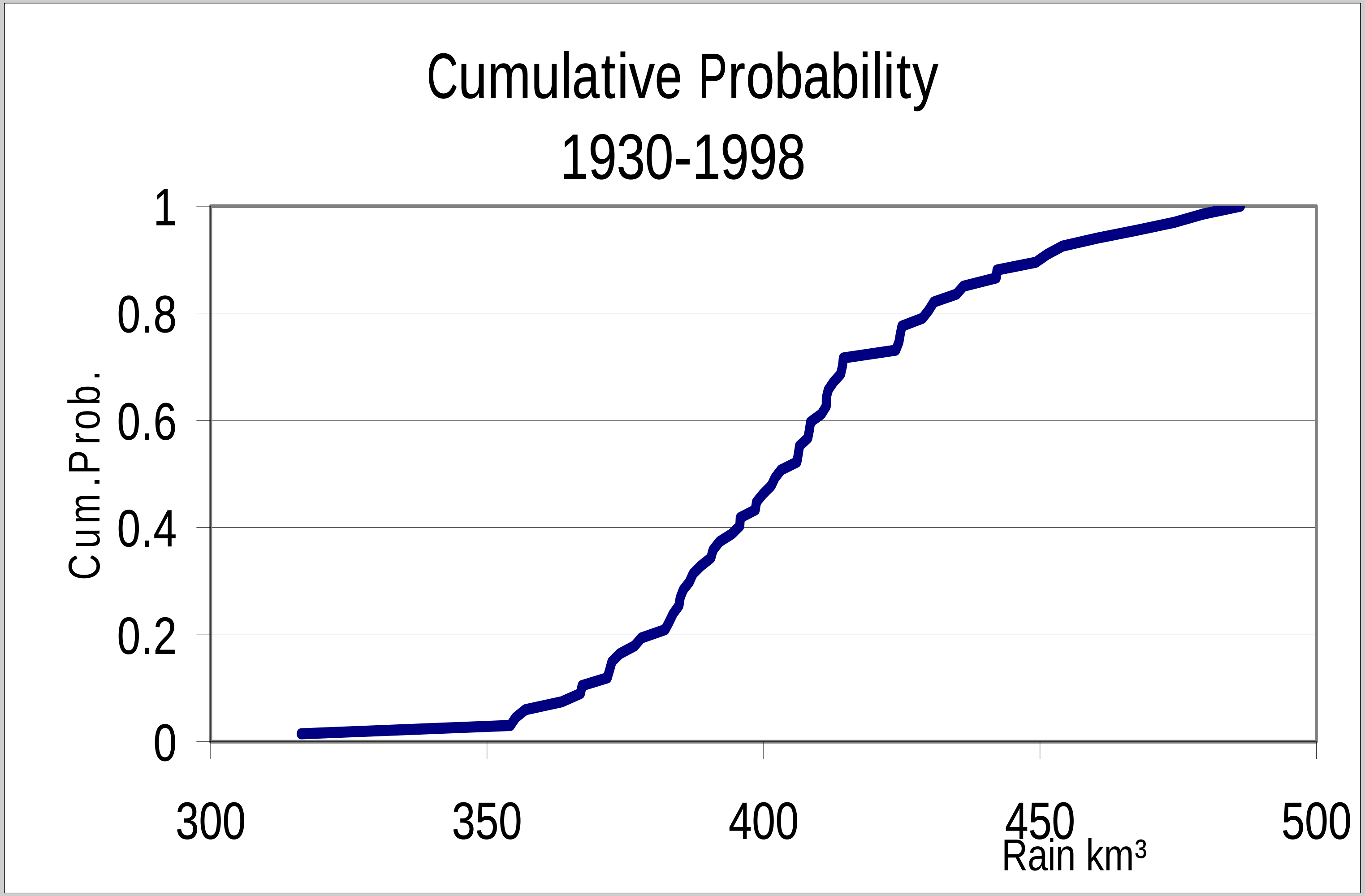
Moving average:

1. $S'_n = S_{n-1} + P_n$
2. $Q_n = \alpha(S'_n + S_{n-1} + S_{n-2}) + \beta(S_{n-3} + \ldots) + \gamma(S_{n-6}) + \delta$
3. $S_n = S'_n - Q$

Simple hydrological models



Boot strapping



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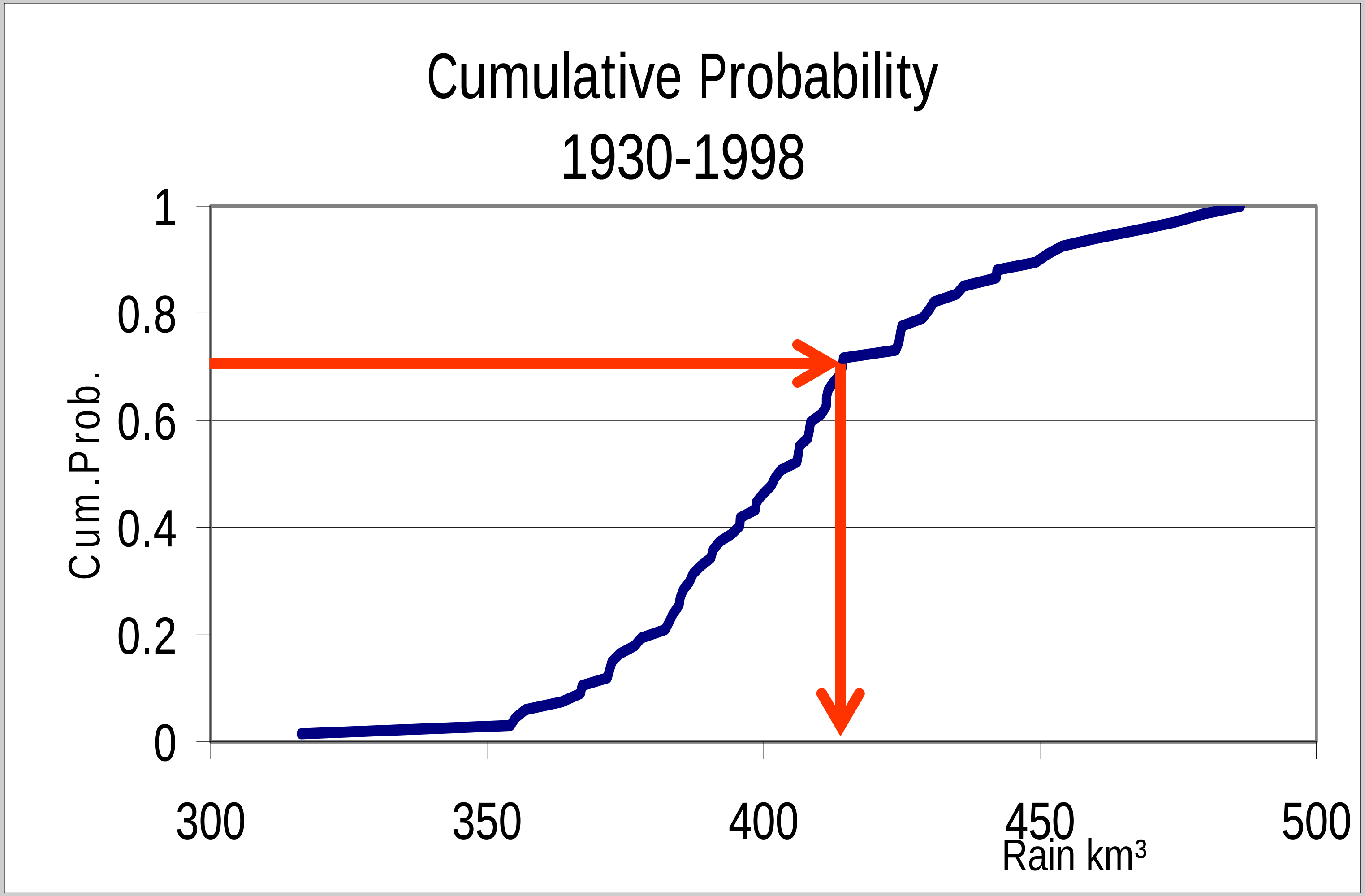
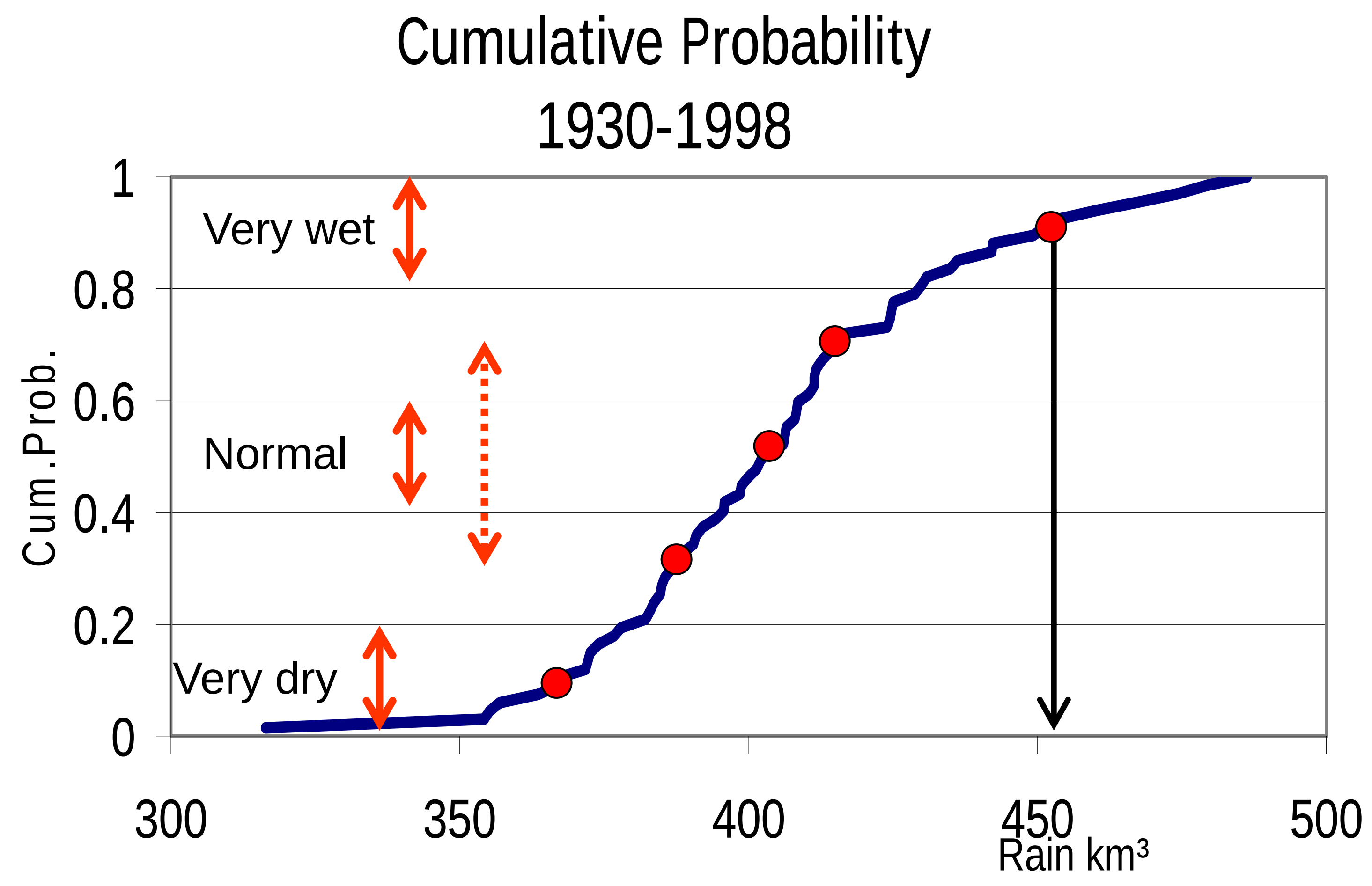


Boot strapping



Boot strapping

- Year method:
  1. Determine relevant percentiles
  2. Random number generator
  3. Random order of:
     - very wet (very cold)
     - wet (cold)
     - normal
     - dry (warm)
     - very dry (very warm)

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Boot strapping

- Year method:

  Scenarios:
  Simply increase (decrease) fraction of dry, very dry, etc.

Boot strapping

- Year method

  Scenarios:

  Simply increase (decrease) fraction of dry, very dry, etc

- Alternative:

  Transform CDF

$$\widehat{p}_1 \propto \mu_1 + \sigma_1 \widehat{\chi}$$

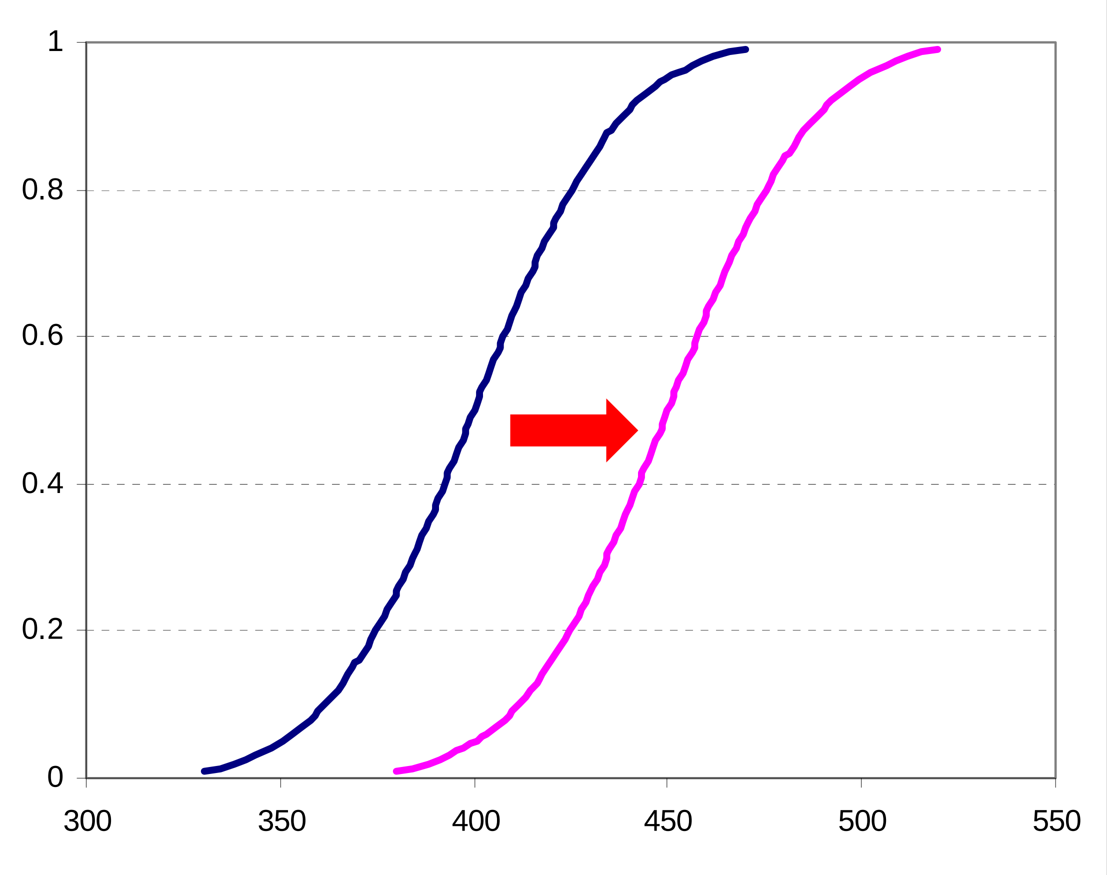
$$\widehat{p}_2 \propto \mu_2 + \sigma_2 \widehat{\chi}$$

$$\widehat{p}_2 \propto \mu_2 + \sigma_2 \frac{\widehat{p}_1 - \mu_1}{\sigma_1}$$

Boot strapping

- Transform

$$\mu_1 = 400 \quad \mu_2 = 450$$

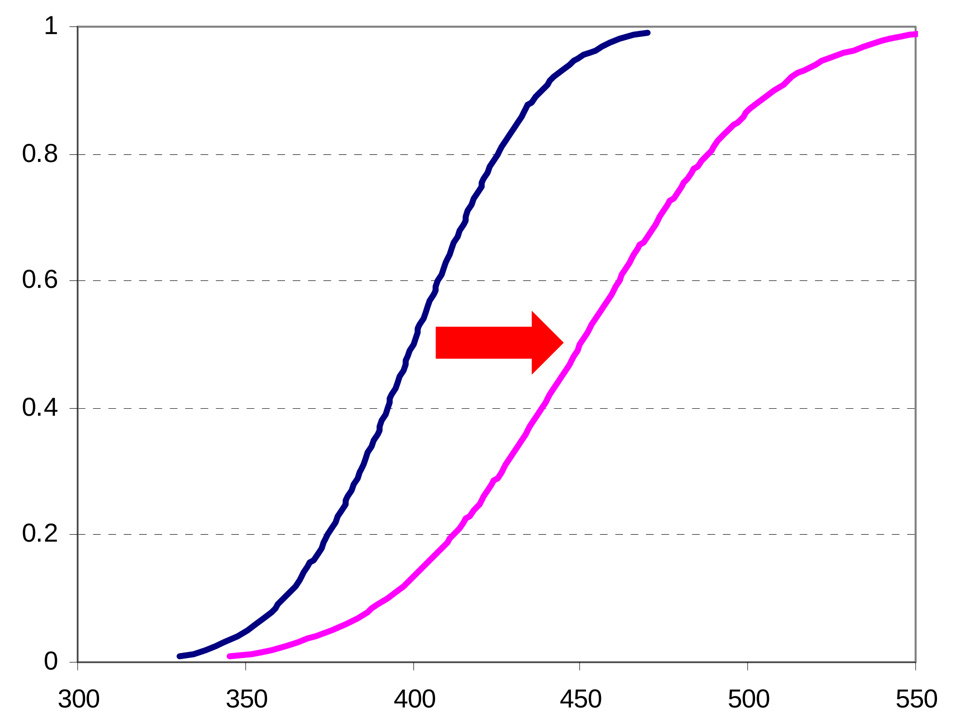


Boot strapping

- Transform

$$\mu_1 = 400 \quad \mu_2 = 450$$

$$\sigma_1 = 30 \quad \sigma_2 = 45$$



Sub-models:

- Water use (quantity & quality):
  - Household
  - Industry
  - Irrigation
  - Ecology
  - Hydropower
  - …

Week 2: Scenarios & Tools

Sub-models, water use:

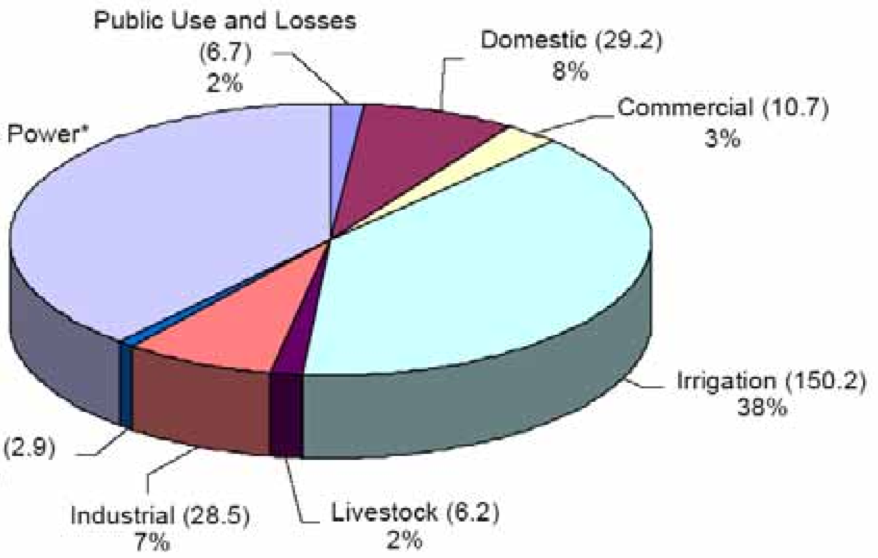
- Household:
  - Western Europe: 130 l/pd
  - Africa urban: 90 l/pd
  - Africa rural: 40 l/pd
  - Demography!

    http://esa.un.org/unpp/

Week 2: Scenarios & Tools

Sub-models, water use:

- Industry:
    - Very specific
    - Quality
    - Heavy industry
    - Cooling



*Category includes water used in the generation of electric power with fossil-fuel, nuclear, or geothermal energy.

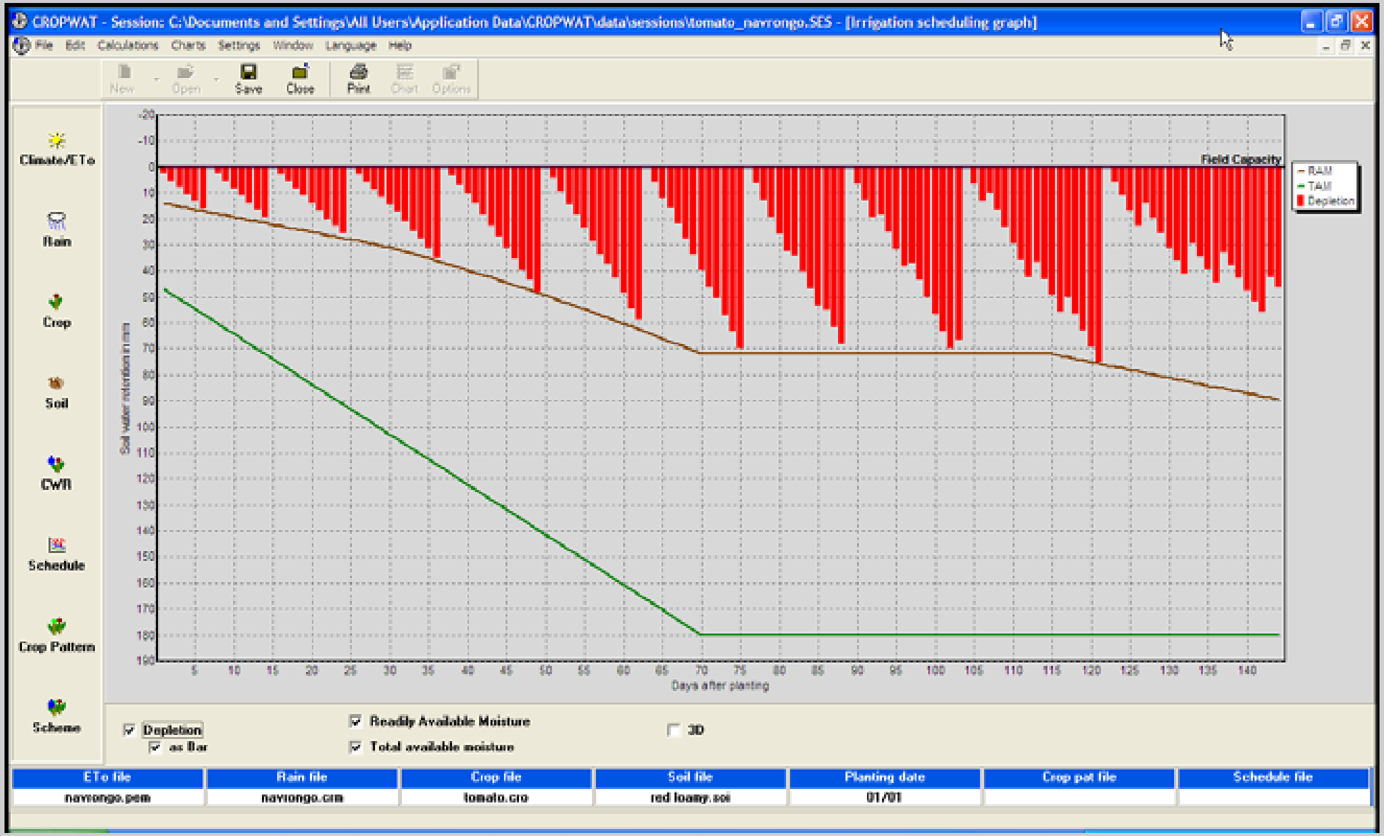
Source: Solley, W.B., R.R. Pierce, H.A. Perlman (1998). Estimated Use of Water in the United States in 1995. Geological Survey Circular 1200.

Water use USA, 1995
http://www.oit.doe.gov/pdfs/100903_news.pdf

Sub-models, water use:

- Irrigation, CropWat:

http://www.fao.org/nr/water/infores_databases_cropwat.html



☑ Depletion
☑ as Bar
☑ Readily Available Moisture
☑ Total available moisture
☐ 3D

ETo file	Rain file	Crop file	Soil file	Planting date	Crop pat file	Schedule file
navrongo.pem	navrongo.crm	tomato.cro	red loamy.soi	01/01		

Sub-models, water use:

- Irrigation:
  - Crop use
  - Efficiencies (30%-60%)

  - Article/Thesis Joshua Faulkner
  - Thesis Ilja van Kinderen (www.smallreservoirs.org)

Sub-models, water use:

- Ecology:
    - Quantity (Minimal Streamflow Requirements)
    - Quality:
        - BOD5
        - Temperature
        - Pesticides
        - Heavy metals
        - Hormones
        - (caffeine)
        - …

Sub-models, water use:

- Ecology:
  - Quantity (Minimal Streamflow Requirements)
  - Quality:
    - BOD5
    - **Temperature**
    - Pesticides
    - Heavy metals
    - Hormones
    - (caffeine)
    - …

Week 2: Scenarios & Tools

Sub-models, water use:

- Ecology:
  - Quantity (Minimal Streamflow Requirements)
  - Quality:
    - QUAL2K
    - WEAP…also temperature!
    - Article Martijn Westhoff, HESS

Sub-models, water use:

- Hydropower:
  - $E_{pot} = m \cdot h \cdot g$ (Joule)
  - $\text{Power} = m \cdot h \cdot g / T$ (Watt)
  - Energy: 1 kWh = 3600×10^3 Joule = € 0.25
  - Efficiency

Sub-models, water use:

- Other models?
- Questions?

Discussion / Q&A:

- What to do for Rhine?
- What to do for Volta?

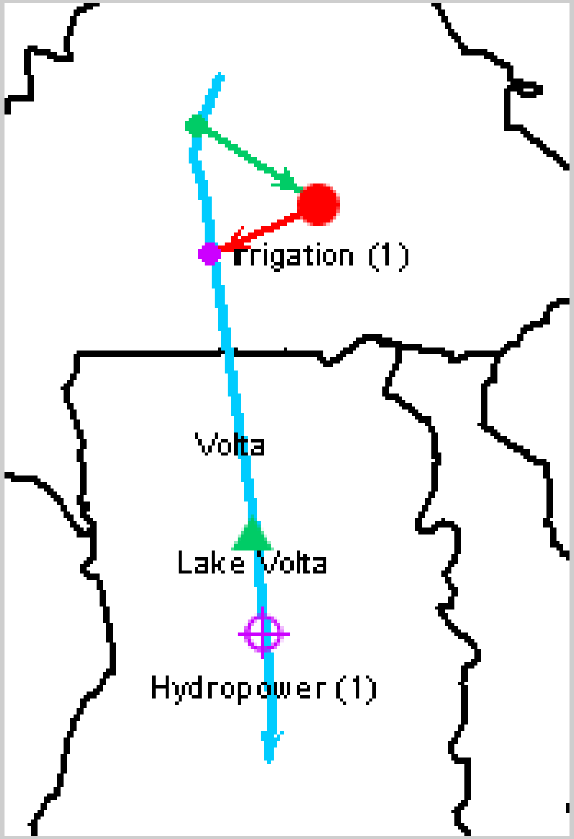
Week 2: Scenarios & Tools

WEAP

- Model development strategy
- mini-Rhine
- mini-Volta

WEAP

- Model development strategy
- mini-Rhine
- mini-Volta



Week 2: Scenarios & Tools

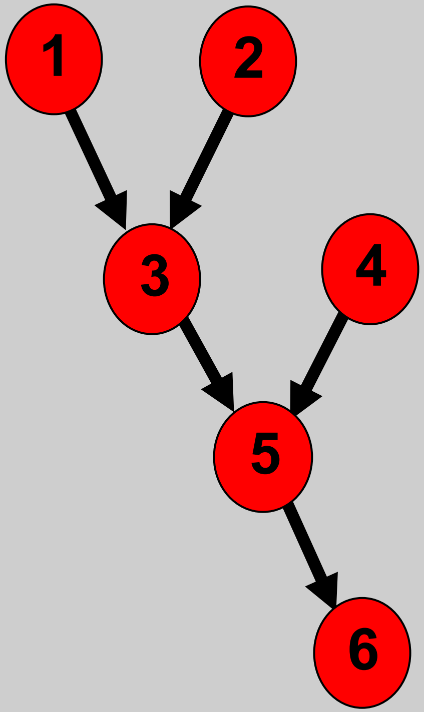
WEAP

- Model development strategy
- mini-Rhine
- mini-Volta

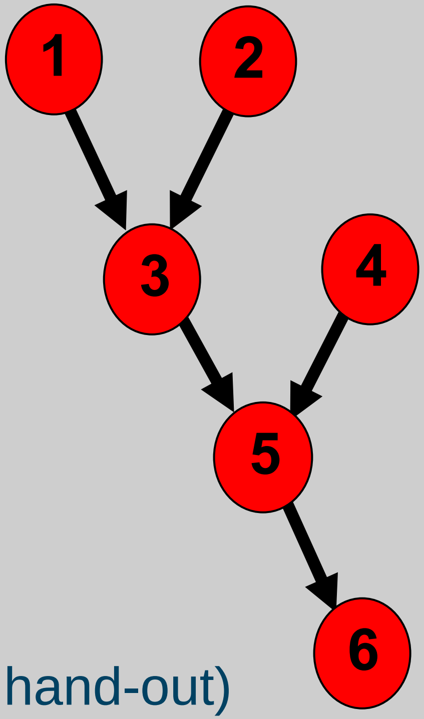
THIS IS NOT A WEAP COURSE!

Graph Theory

- Overview
- Exercise



Graph Theory



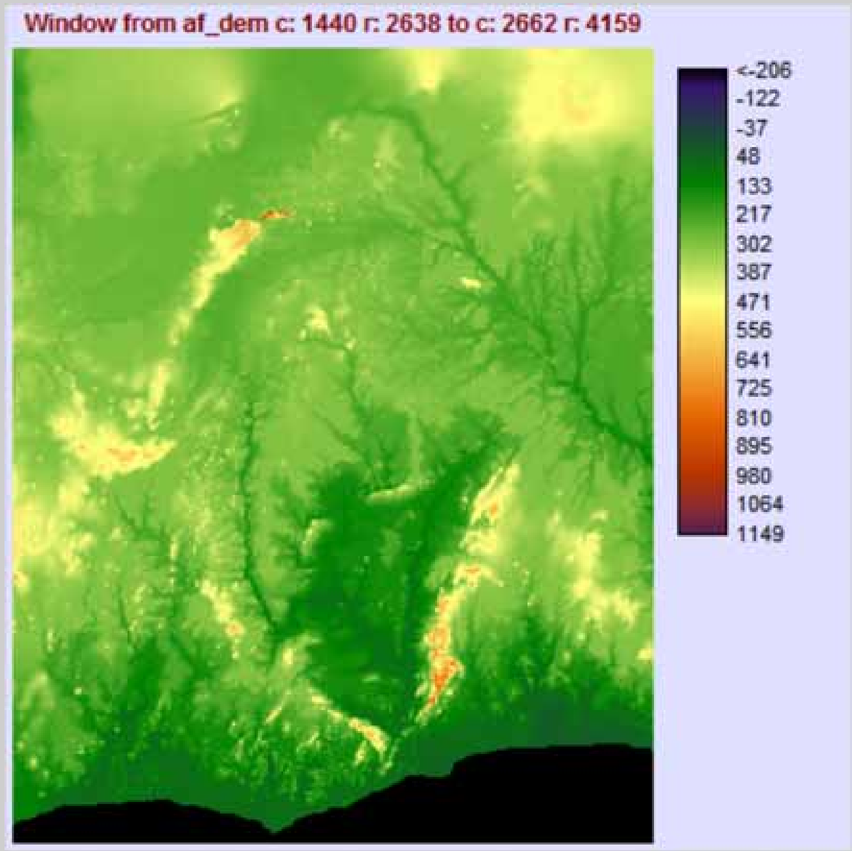
- Nodes & links/edges
  - Directed vs non-directed
  - Cyclic vs non-cyclic
  - Trees
  - Incidence & connectivity matrix (Excel, hand-out)

Week 2: Scenarios & Tools

Graph Theory

- DEM Analysis

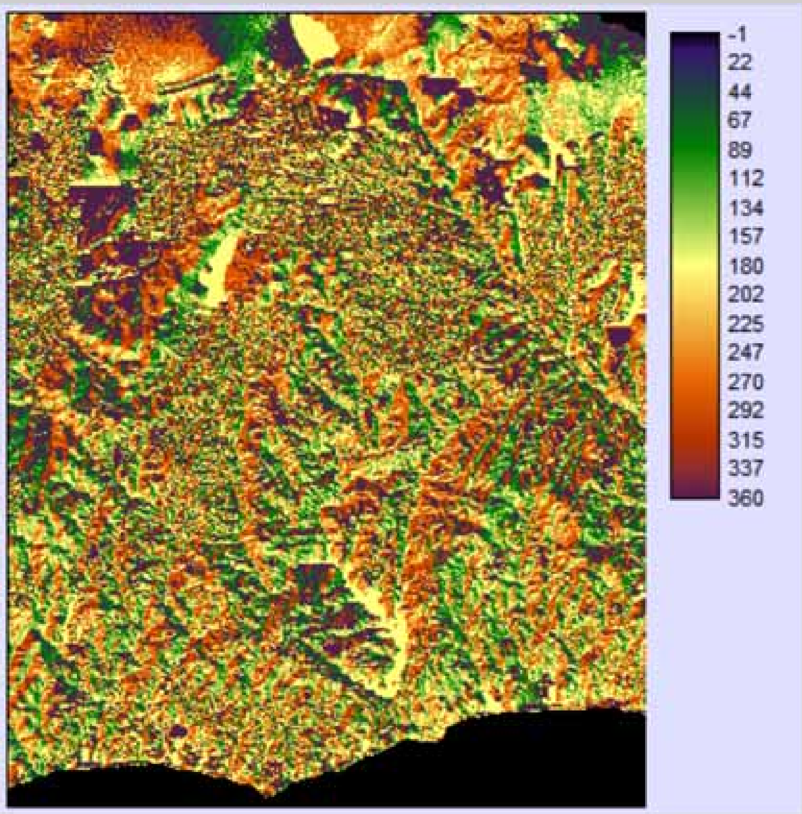
  1. DEM


Window from af_dem c: 1440 r: 2638 to c: 2662 r: 4159

IWM Fall 2013

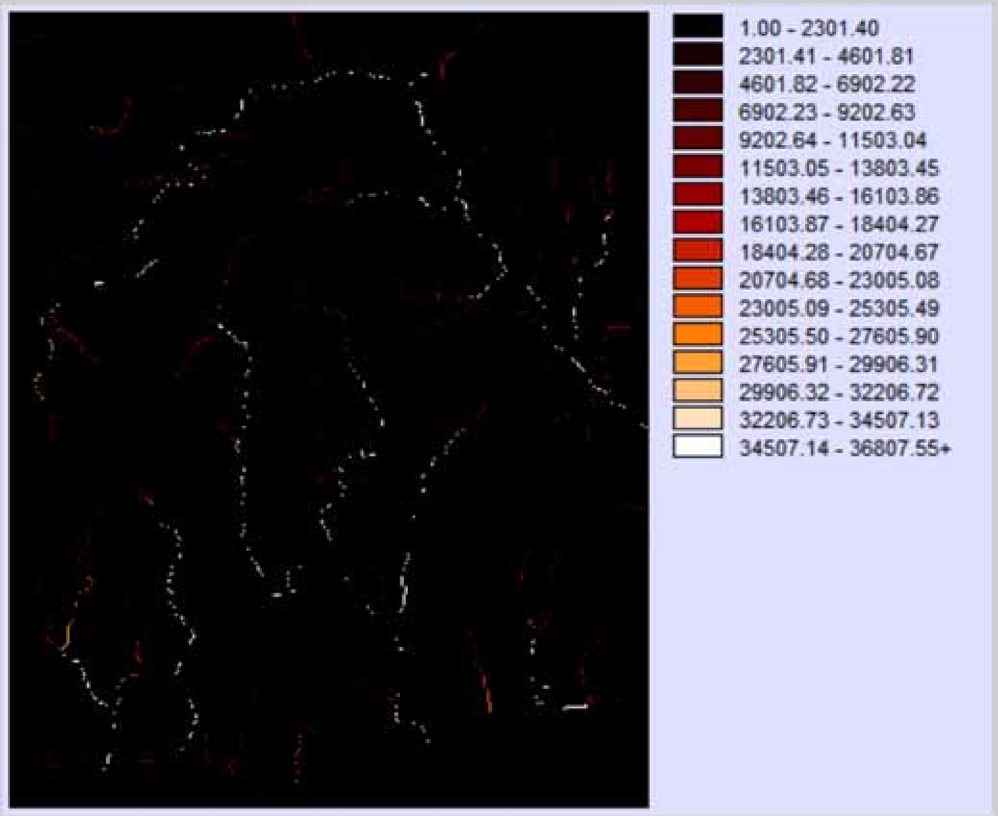
Graph Theory

- DEM Analysis
  1. DEM
  2. Flow direction



Graph Theory

- DEM Analysis
  1. DEM
  2. Flow direction
  3. Invert/sum columns



Graph Theory

- DEM Analysis
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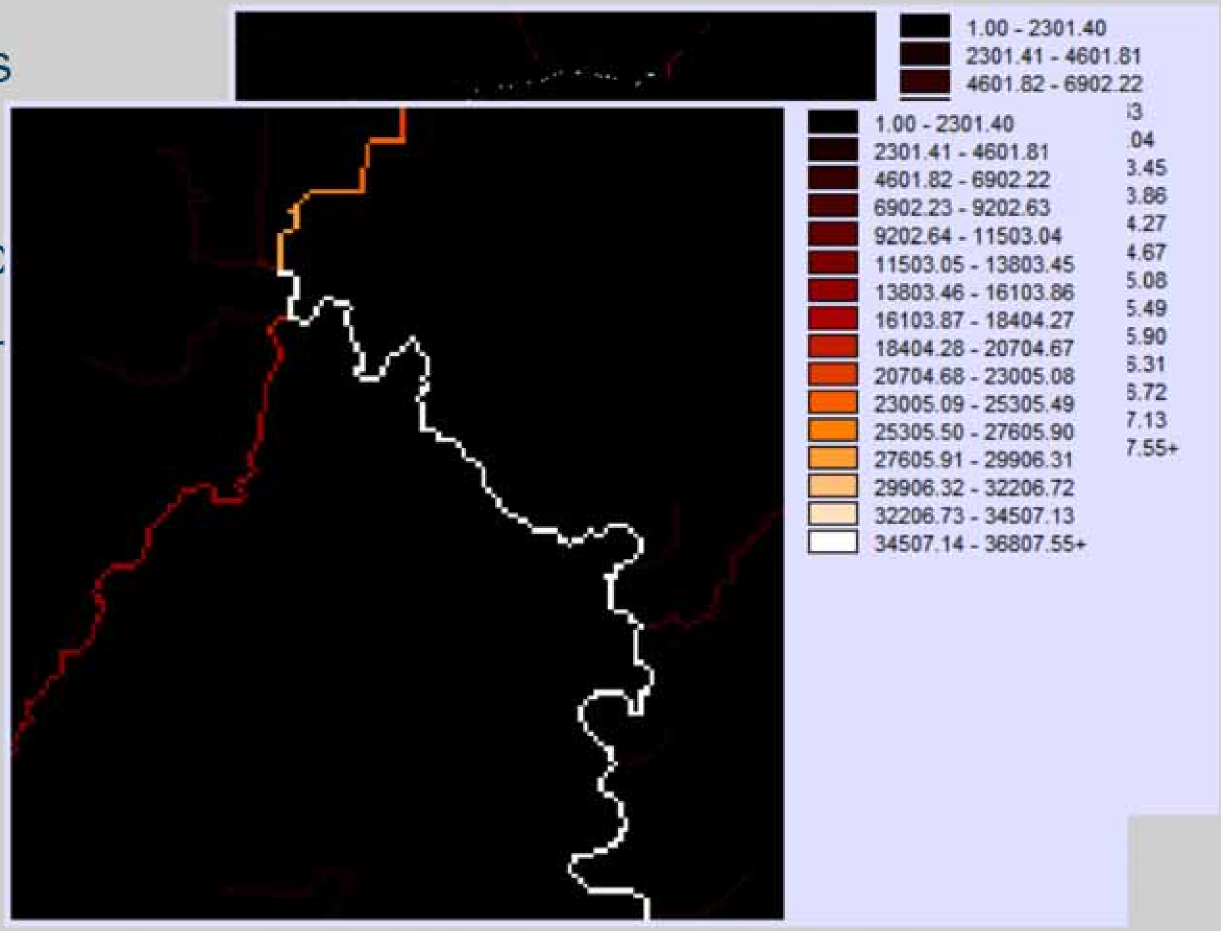
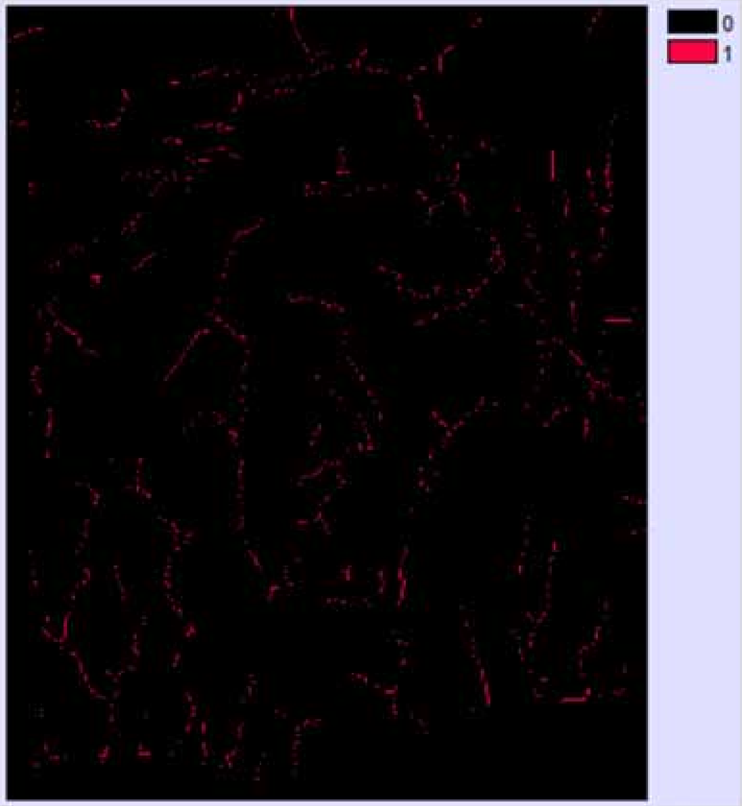
  3. Invert/sum



ZOOM

Graph Theory

- DEM Analysis
  1. DEM
  2. Flow direction
  3. Invert/sum columns
  4. River network



Week 2: Scenarios & Tools

Graph Theory

- DEM Analysis
  1. DEM
  2. Flow directio
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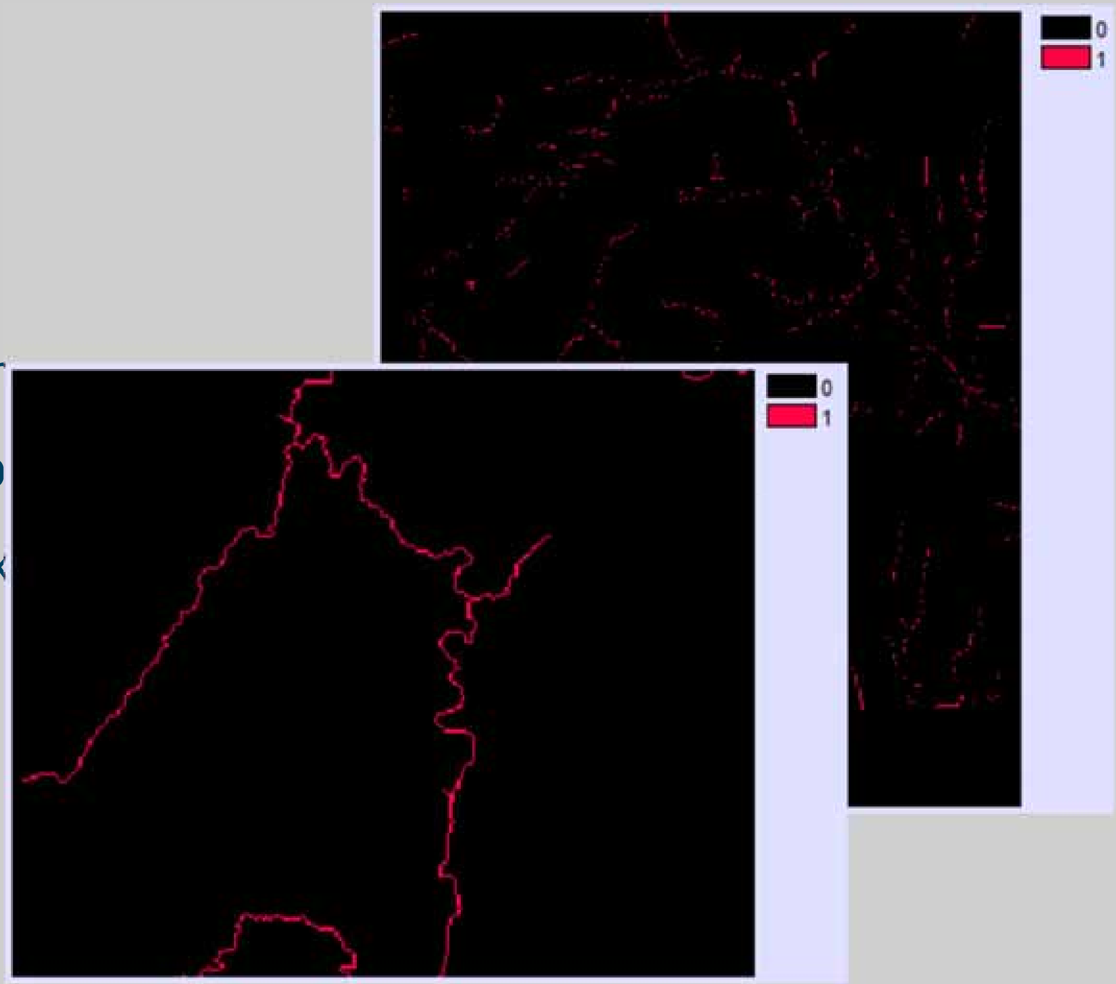
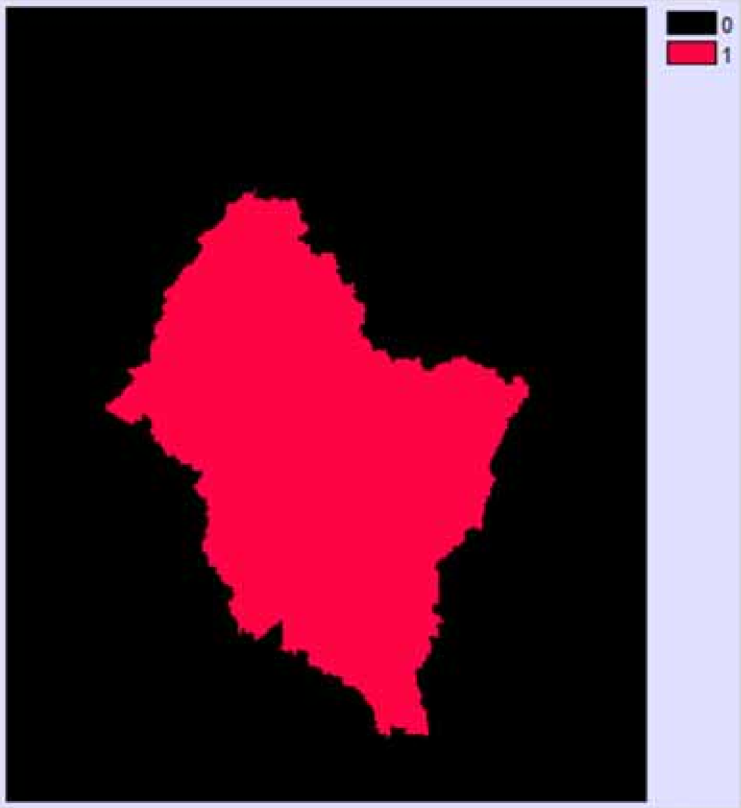


ZOOM

Graph Theory

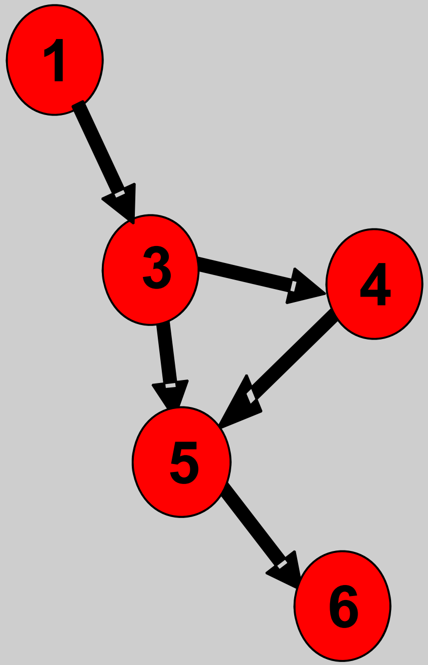
- DEM Analysis
  1. DEM
  2. Flow direction
  3. Invert/sum columns
  4. River network
  5. Watershed



Graph Theory

- Exercise

How does this work for a WEAP-like node network?



Use percentages of flow.