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GLOWA Volta

# The GLOWA Volta Project

# From Concepts to Application

Paul L.G. Vlek and Charles Rodgers

# GVP Overview

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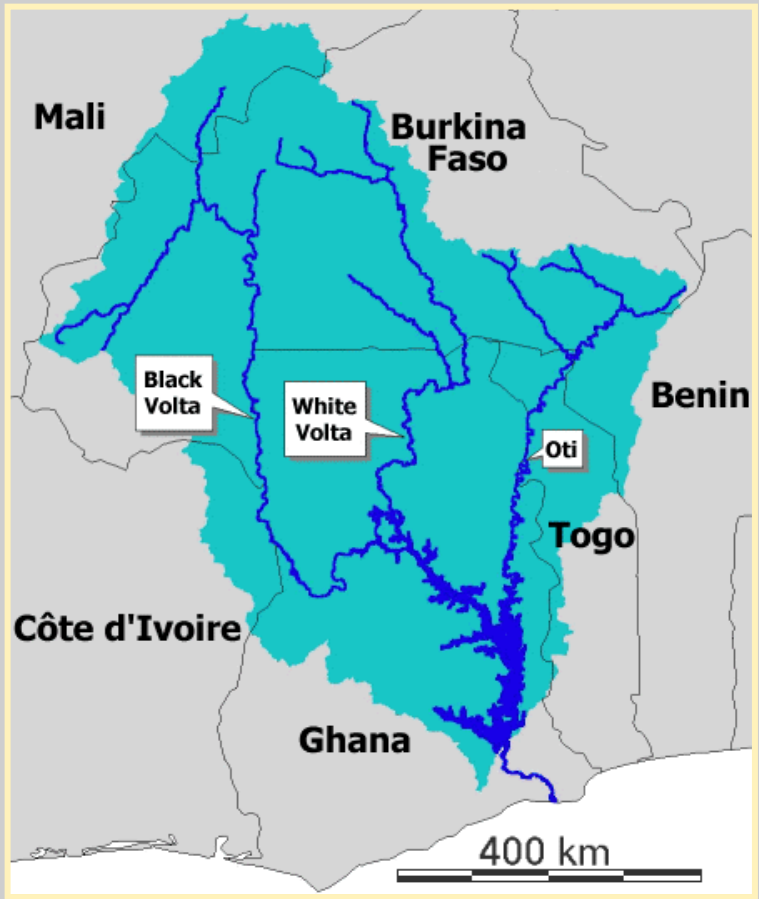
## Objectives of the GLOWA Volta Project

- **Integrated analysis** of the physical and social determinants of the hydrological cycle
- Scientifically sound **Decision Support System** for the assessment, sustainable use and development of the water resources of the Volta Basin
- **Development of „Human Capital“** via advanced education and training, co-operative research and stakeholder participation




## Volta Basin Setting

- 400,000 km²
- 6 riparian states
- 15-20 million people, $800/yr
- Average rain 1000 mm/year
- 9% to rivers (runoff, baseflow)
- Lake Volta – largest artificial

# GVP Overview

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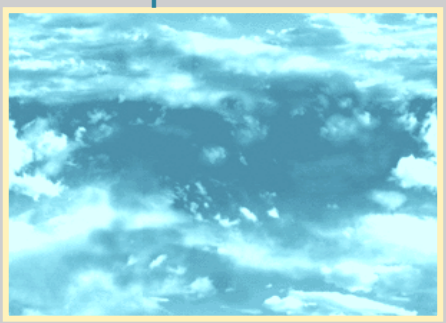
Atmosphere



Land use

Water use

## Water related issues

- Climate variability, regional & global
- Rapid land use change
- Competition for water
  - Hydropower
  - Mining/Industry
  - Irrigation
  - Households

# Model Integration, DSS

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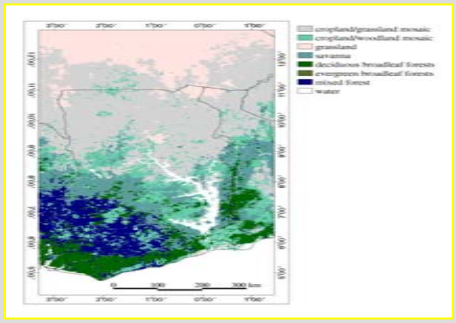
## Climate, Land Use, Hydrology

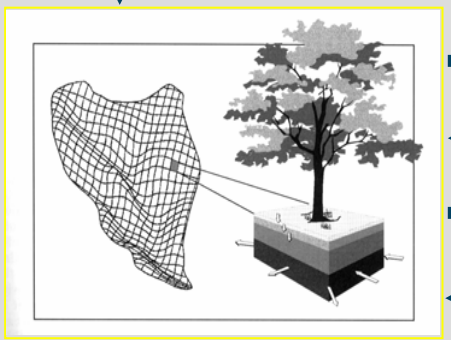


LUDAS: Land Conversion

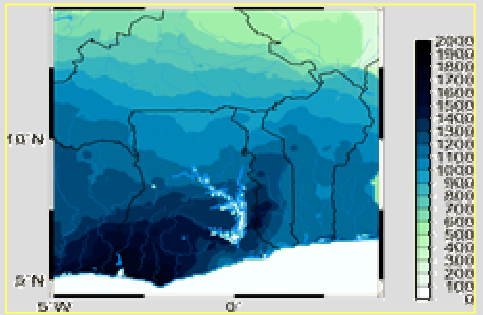
Remote Sensing

Instrumentation

WaSIM:



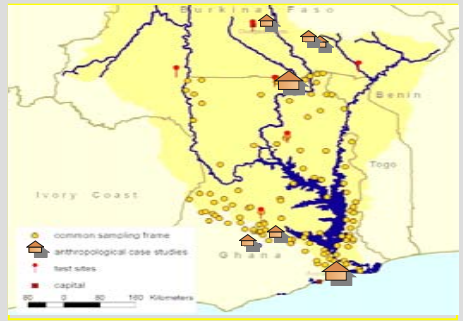
Hydrology



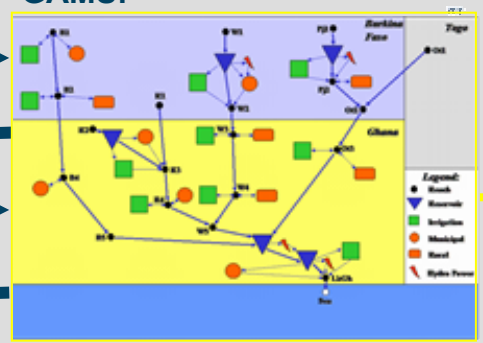

MM5: Mesoscale Climate

## Economics, Institutions, Stakeholders

Field Sur-veys




GAMS:



Integrated Basin Model


Institutional Analysis

Decision Support System

Ministers

WRC

Water Board

WATSAN

DA

VRA

Donors

# Land Conversion

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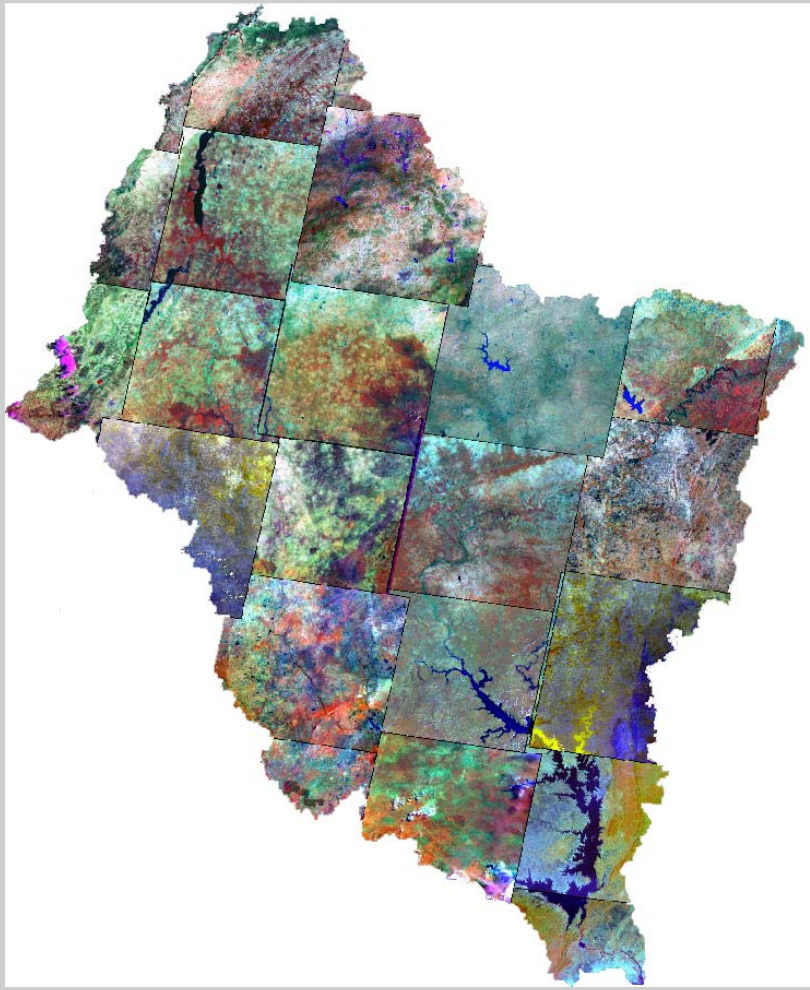
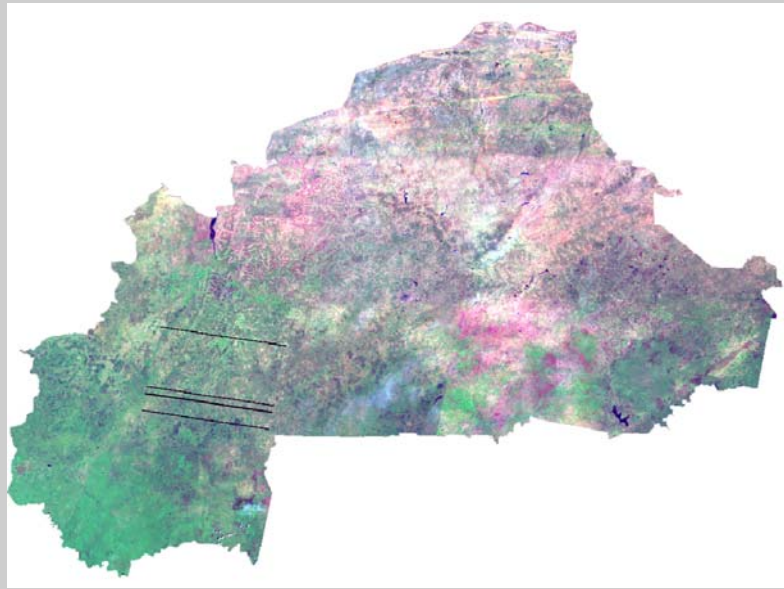
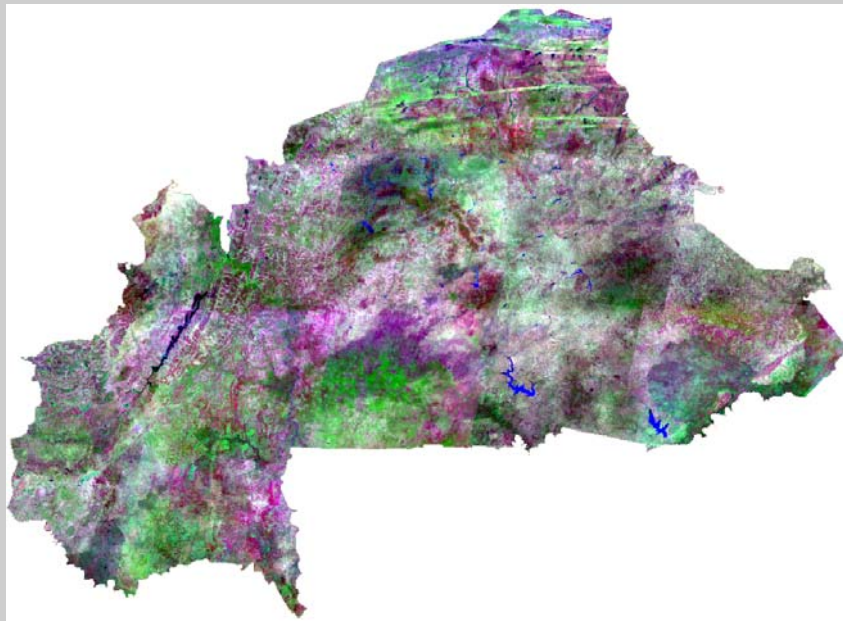
## Assembly & preprocessing of Landsat mosaics 1974-84-90-2000







# Land Conversion

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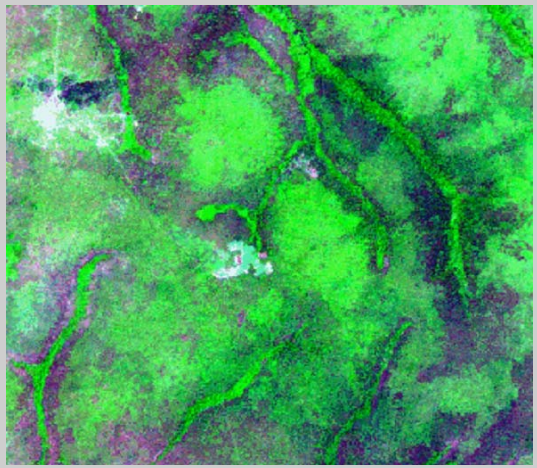
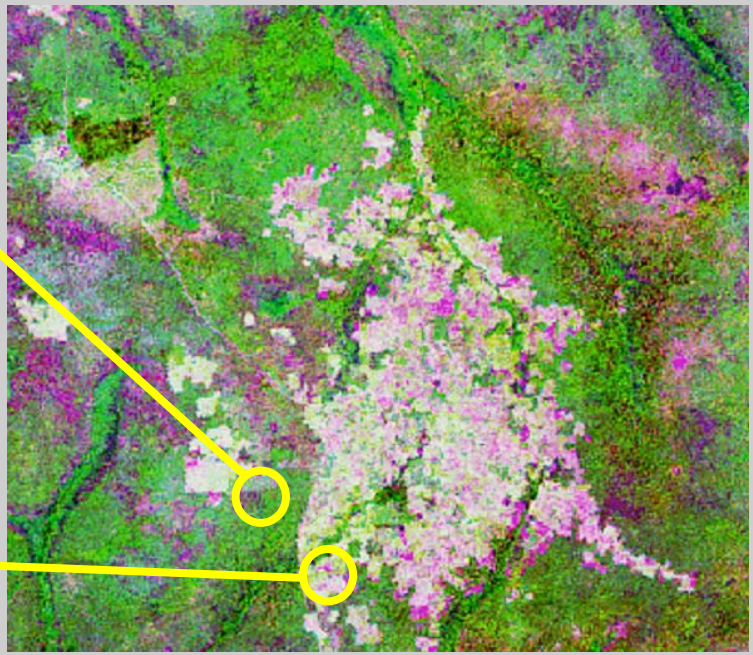
## Supervised Classification of Images

1984



1999



# Land Conversion

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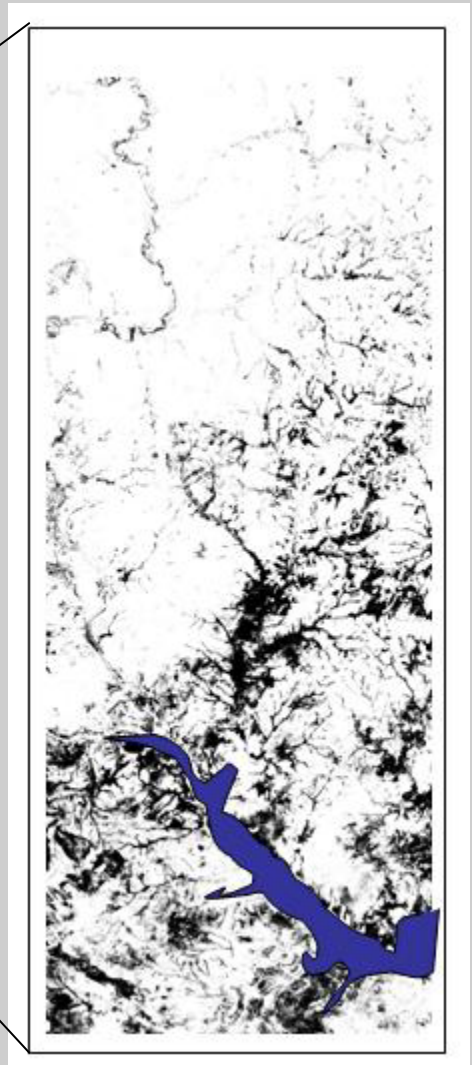
## Example of an Output:

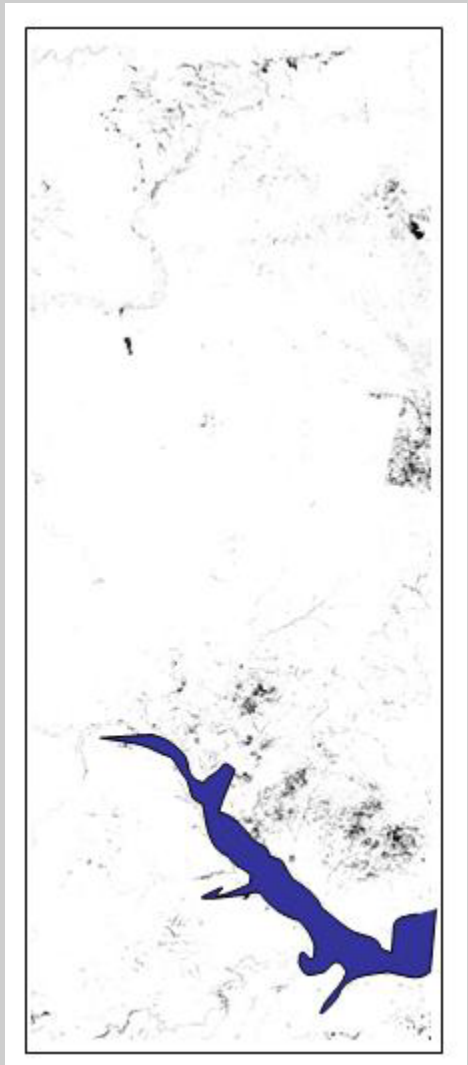
## Deforestation in Ghana

## 1991 – 2000


1991



2000



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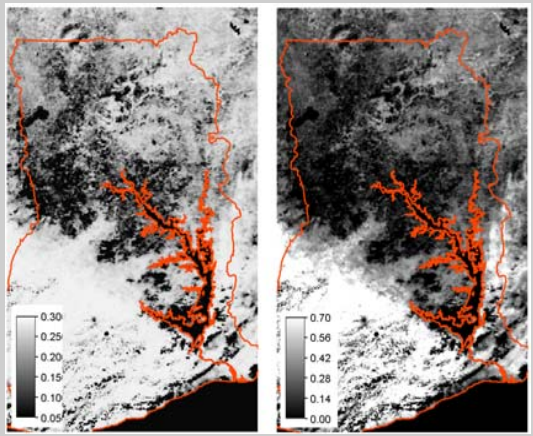
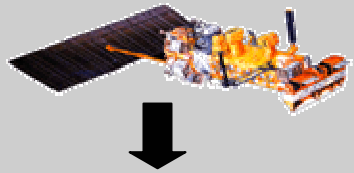
# Assimilation of Satellite Derived Land Surface Properties into Hydrological and Atmospheric Model

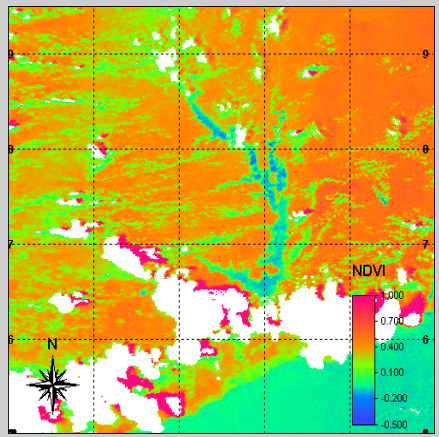



LAI $z_{0m}$



**Spatial information on**

- Elevation, land use
- NDVI, SAVI
- LAI
- Albedo α, emissivity ε
- Roughness length $z_{0m}$
- Vegetation cover




NDVI

**MM5**
3-D Atmospheric Model

**WaSiM**
Distributed Hydrological Model

# Scaling Methodology
# Dissertation of Joseph Intseful



## Derivation of scaling laws for effective values of

| Parameter | Method |
|---|---|
| Surface emissivity $\varepsilon$ | Arithmetic mean |
| Surface albedo $\alpha$ | Arithmetic mean |
| Roughness length $z_0$ | Geometric mean |
| Clapp-Hornberger soil parameter ***b*** | Geometric mean |
| Minimum stomatal resistance ***Rcmin*** | Geometric mean |
| Plant insolation factor ***Rgl*** | Geometric mean |
| Leaf area index ***LAI*** | Arithmetic mean |
| Vapour saturation factor ***Hs*** | Geometric mean |

- Stand-alone SVAT Model (1D SVAT)
- Full Mesoscale Meteorological Model (3D SVAT)

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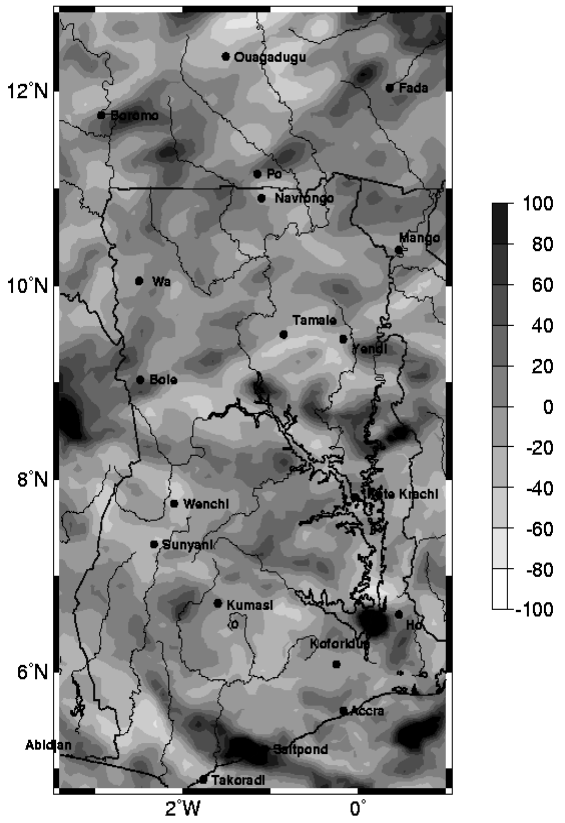
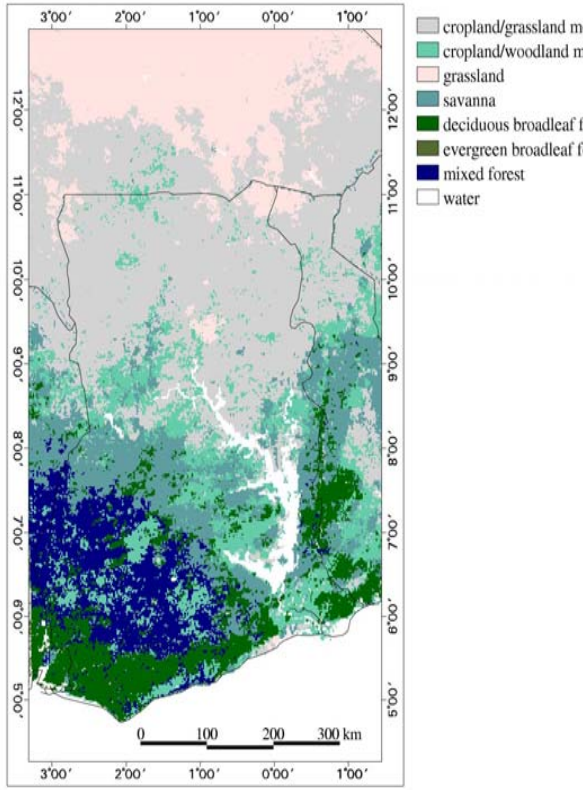
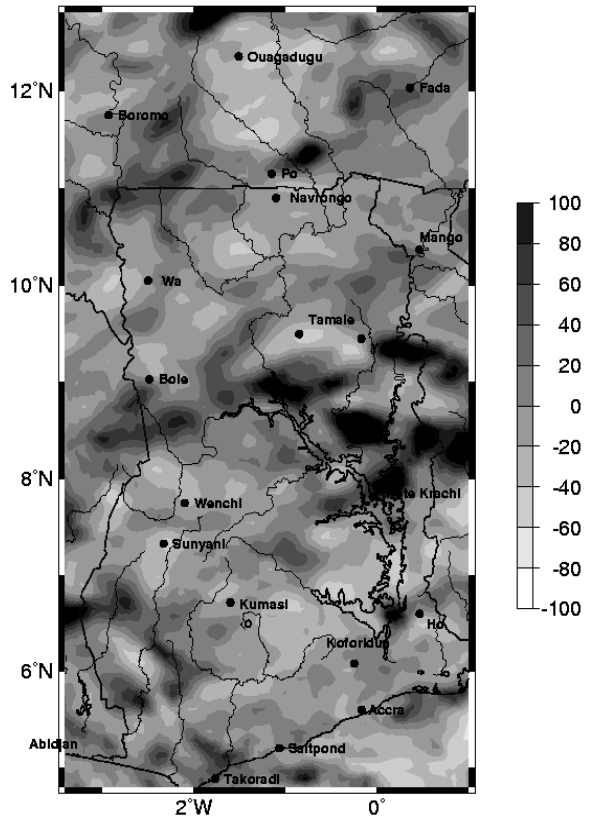
# Impact of Land Use Change on Precipitation

Change in precipitation [%], 15.7.-14.8.1998




Crop Woodland Mosaic → Shrubland

Crop Woodland Mosaic → Grassland

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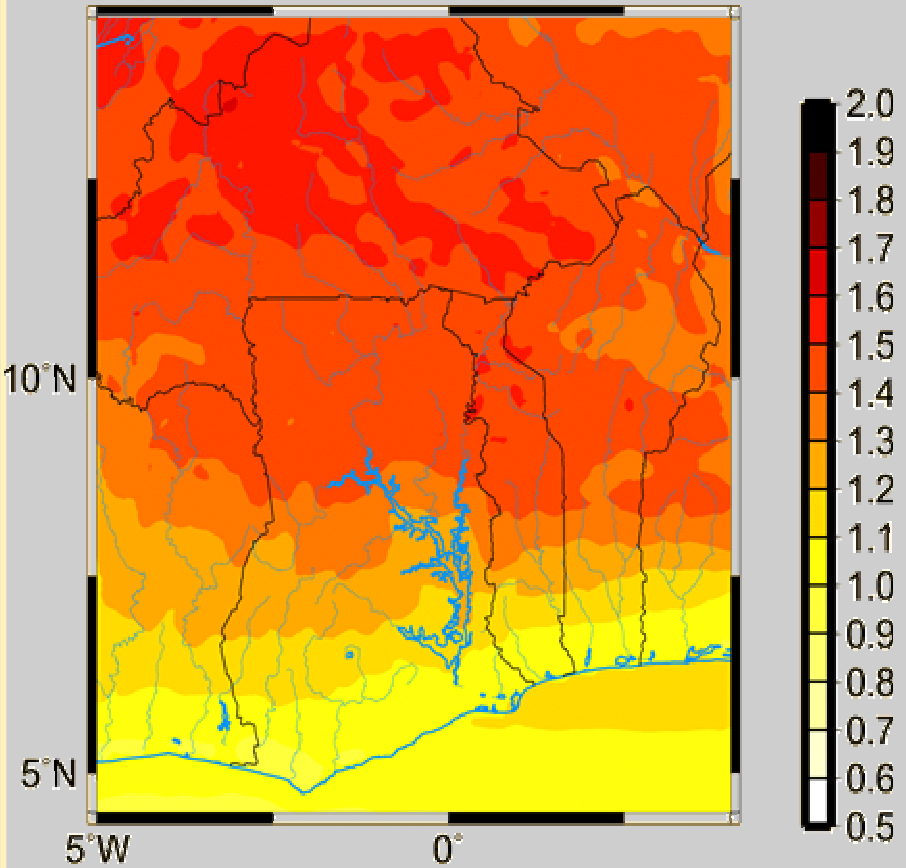
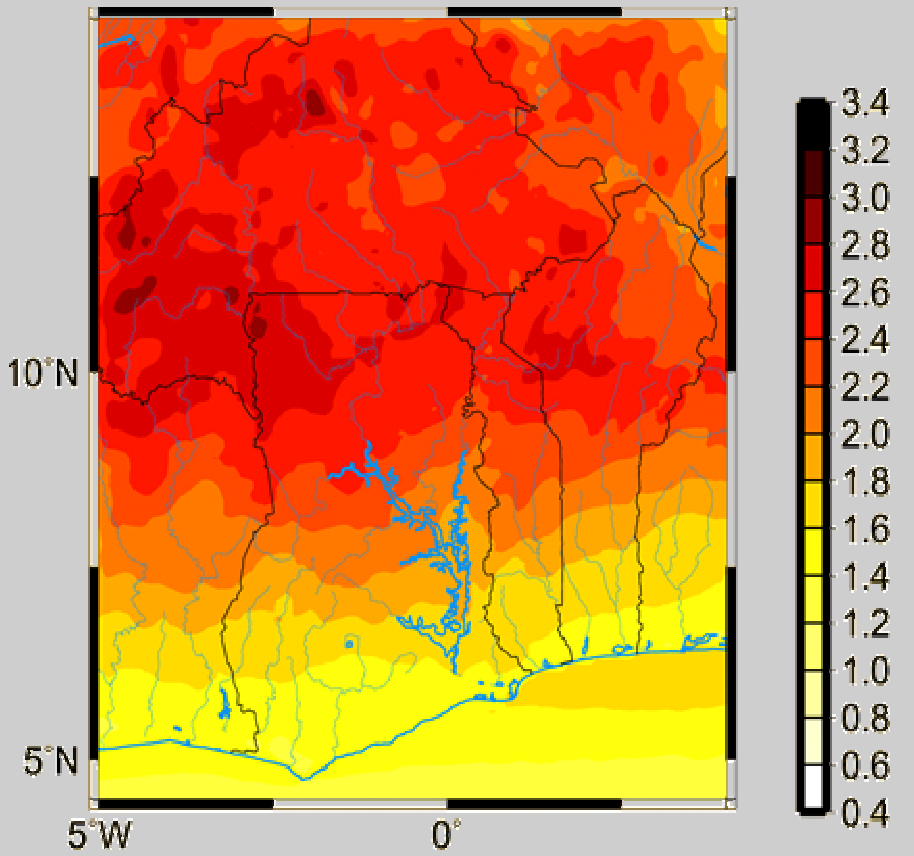
## Temperature Change [°C] 2030/2039 – 1991/2000




Annual mean




April

# Regional Climate Simulations

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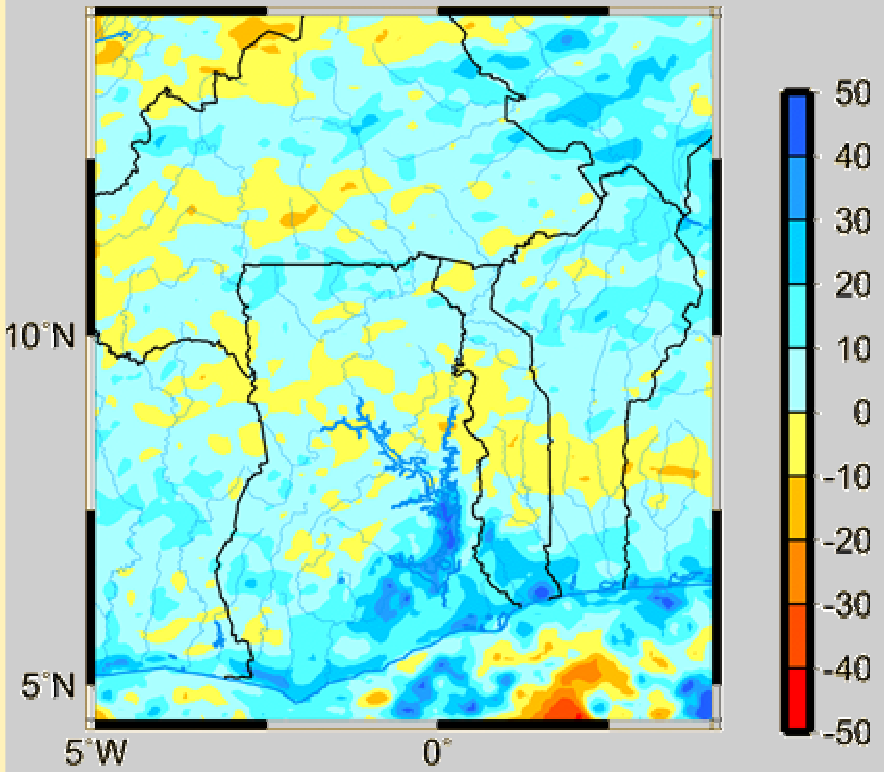
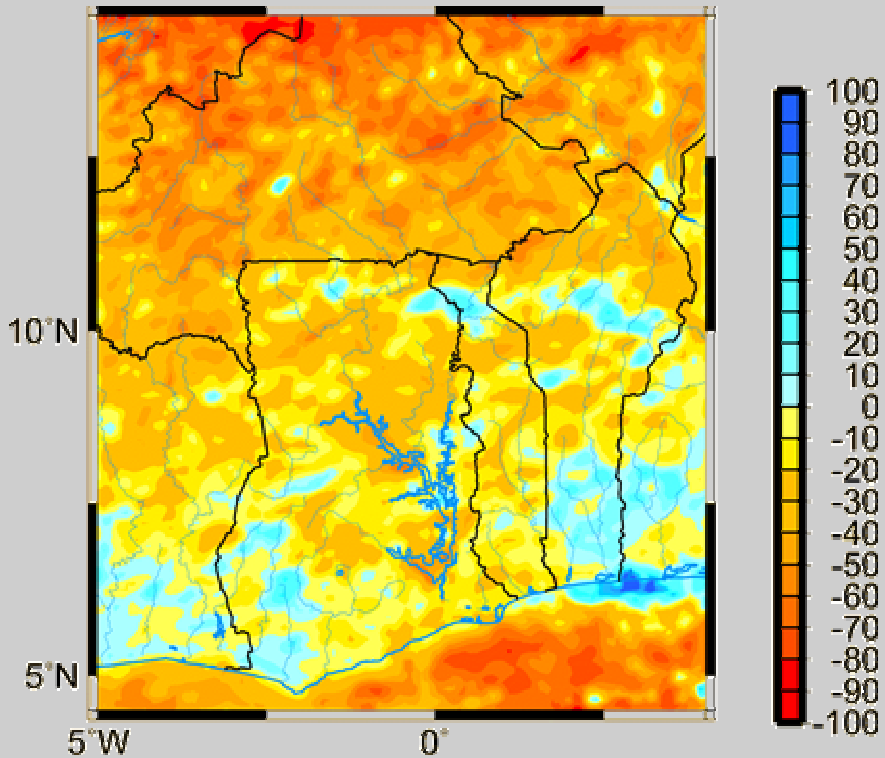
## Precipitation Change [%] 2030/2039 – 1991/2000




Annual mean




April

# Regional Climate Simulations

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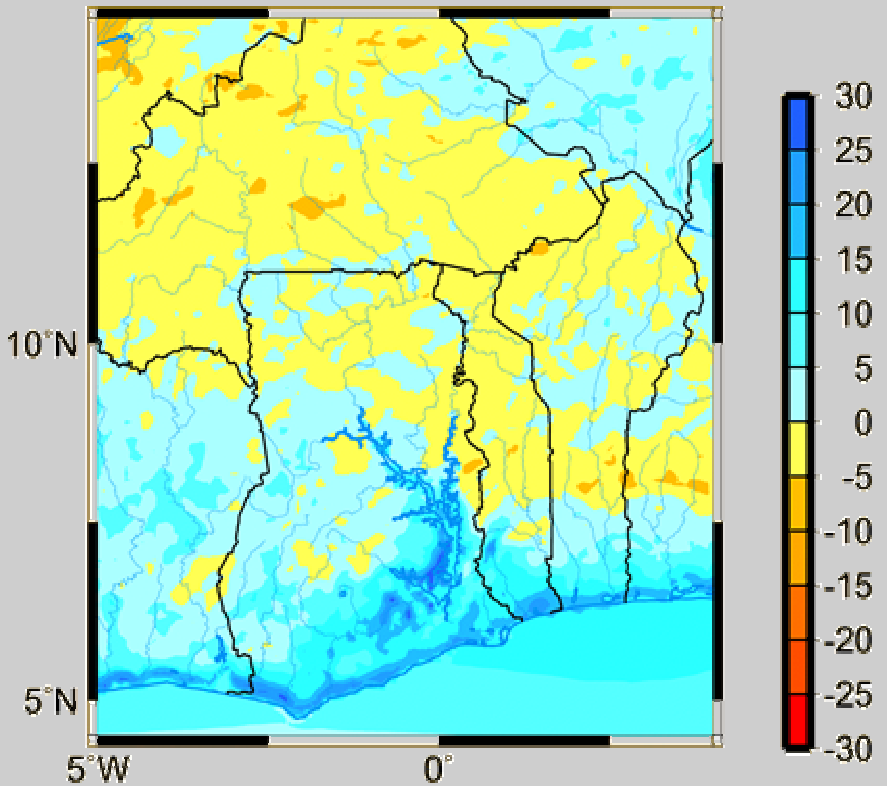
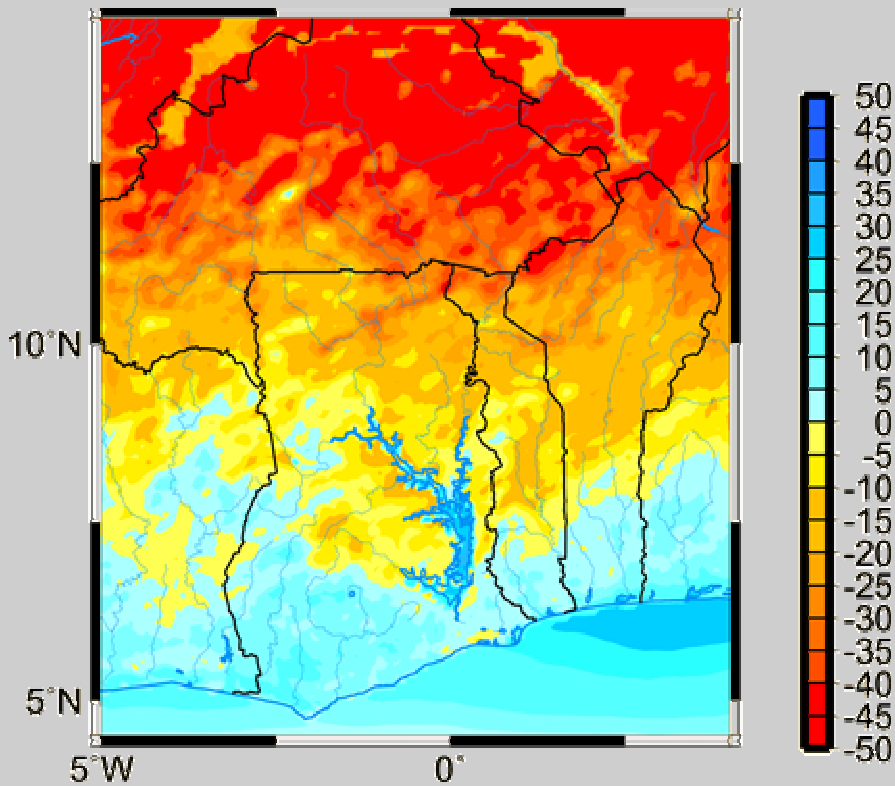
## Evapotranspiration Change [%] 2030/2039 – 1991/2000




Annual mean




April

# Regional Climate Simulations

ZEF

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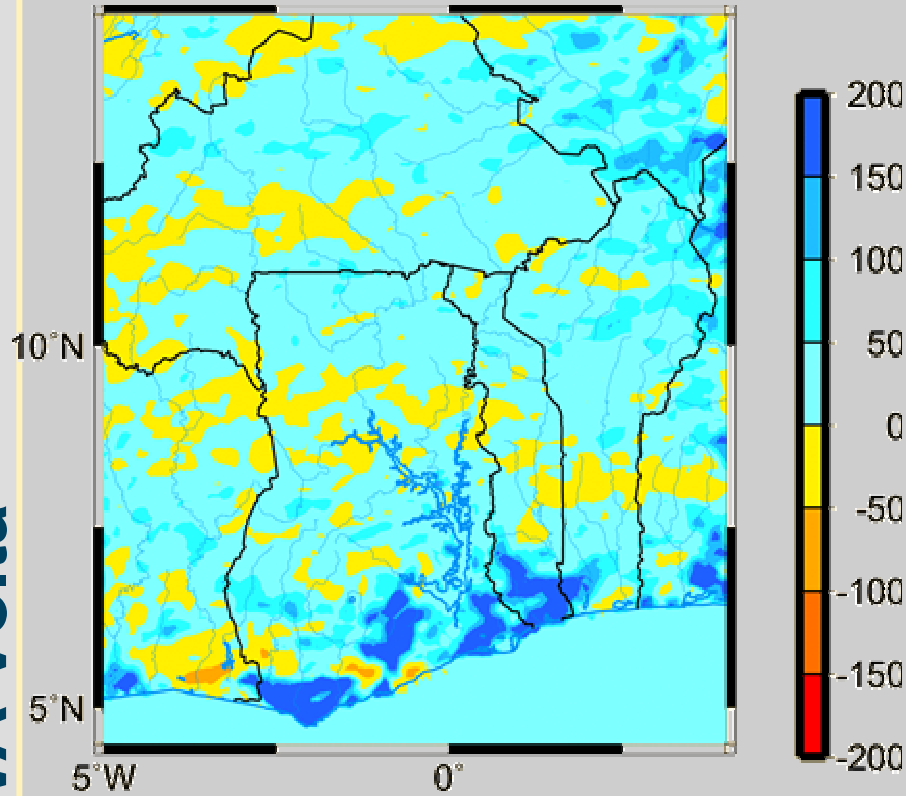
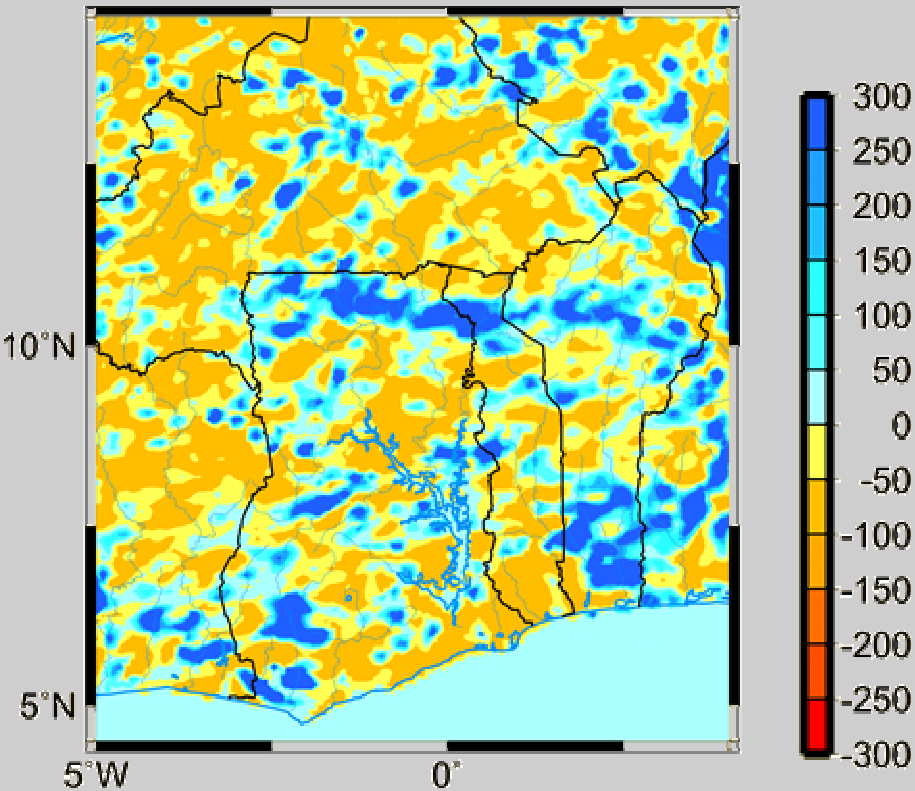
## Surface Runoff Change [%] 2030/2039 – 1991/2000




Annual mean




April

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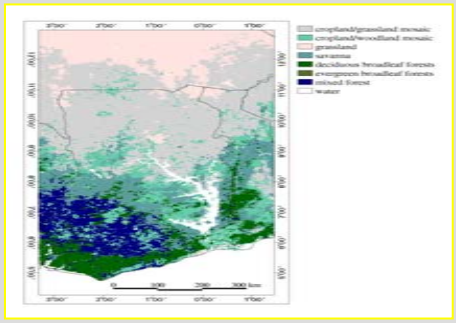

LUDAS: Land Conversion

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Instrumentation

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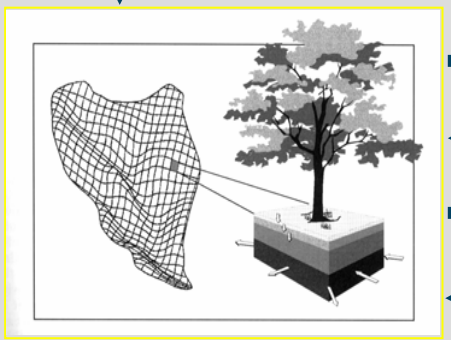
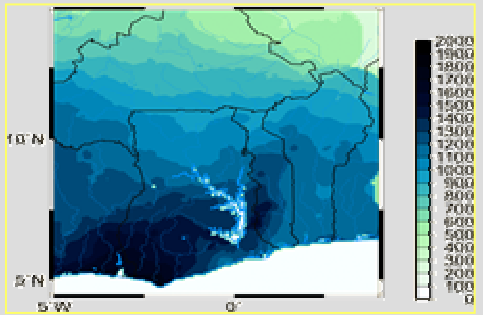


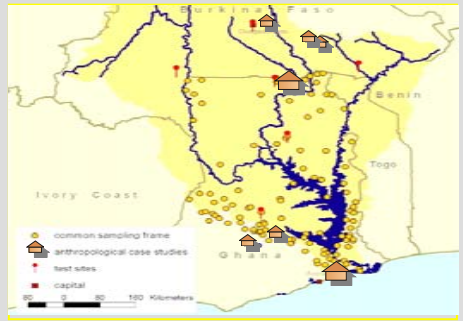
Hydrology



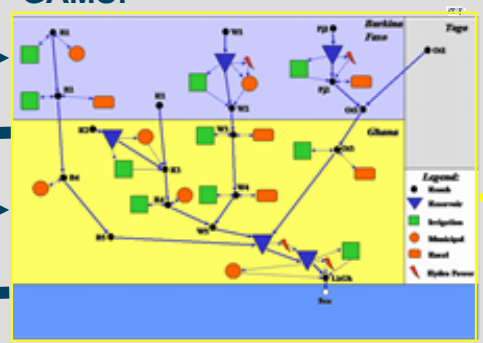

MM5: Mesoscale Climate

## Economics, Institutions, Stakeholders

Field Sur-veys




GAMS:



Integrated Basin Model


Institutional Analysis

Decision Support System

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# Integration of Atmosphere and Surface Hydrology

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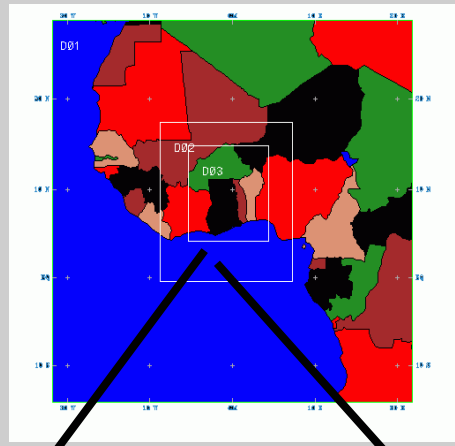
## Coupled Simulations; MM5 and WaSIM

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Global Radiation

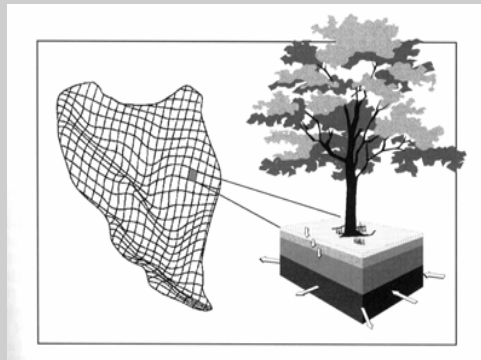
**MM5**
3-D Atmospheric Model




2.8x2.8° → 9x9 km² Resolution

**WaSiM**
Distributed Hydrological Model

- Orography
- Land Use
- Soil Properties
- Aquifer Properties
- Flownet Structure



1km²x1km² Resolution

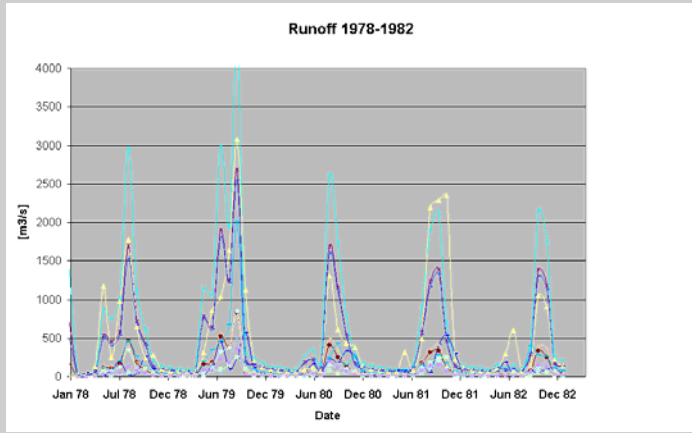
Evapo-transpiration

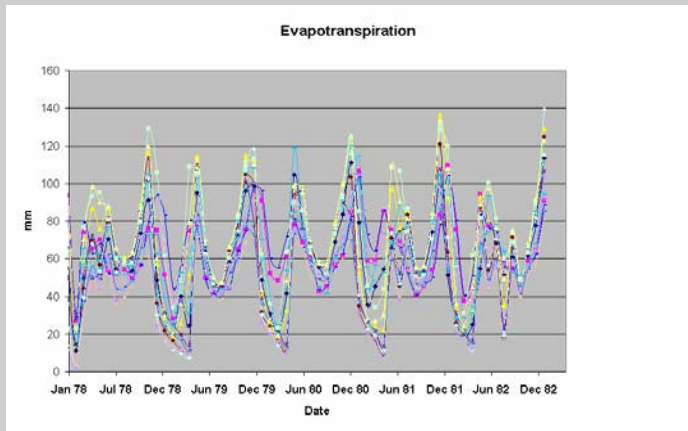
Infiltration

Surface Runoff

Groundwater Flow

# Coupled Hydrological-Meteorological Simulations MM5, WaSIM


- Rivers, land use and gauges of the Volta Basin as applied in hydrological model WASIM
- Coupled system allows estimation of change of river flow, recharge, evapotranspiration, etc.

GLOWA Volta

# Instrumentation – Field Sites

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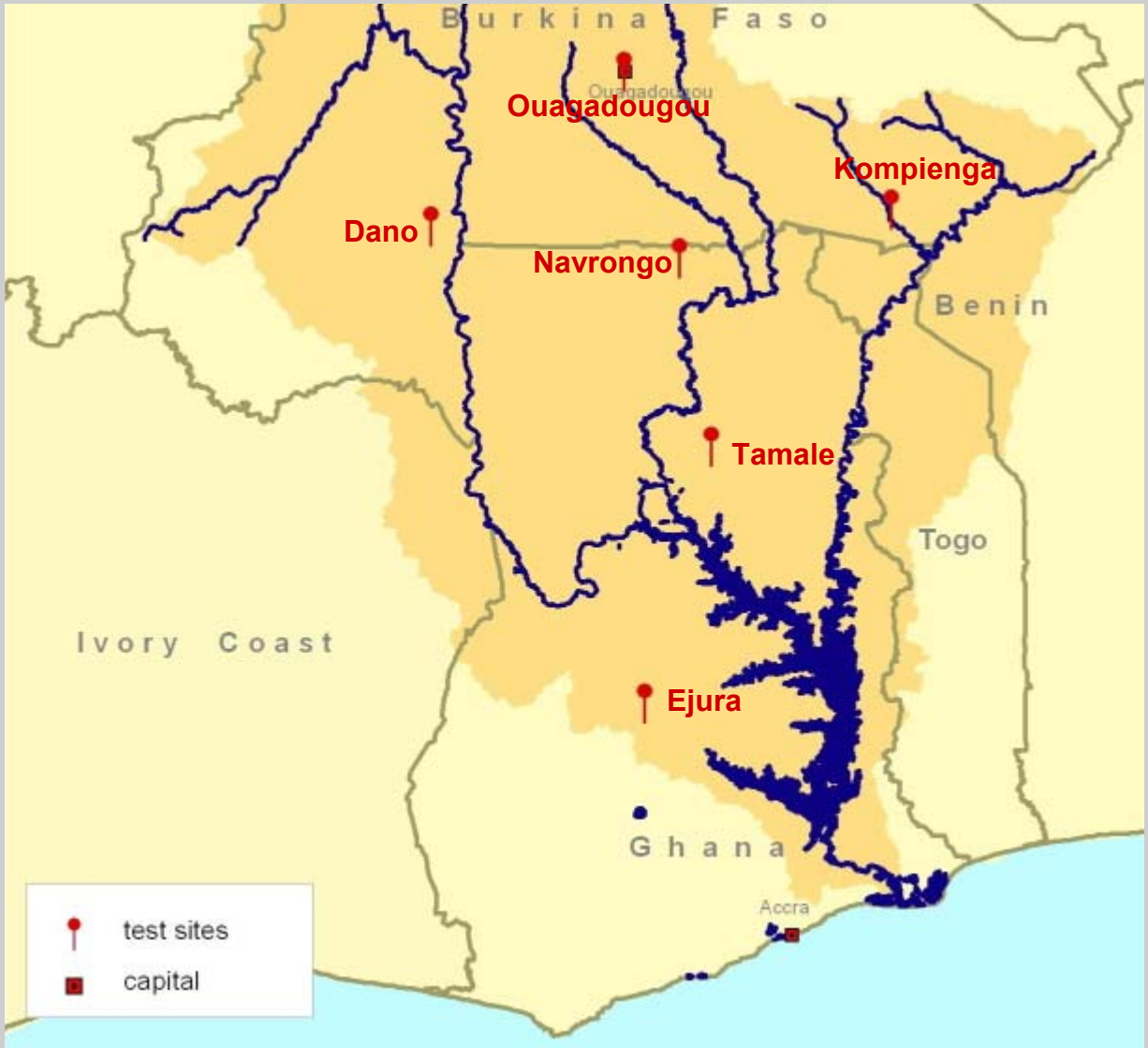
GLOWA Volta




## IOP 2004

Precipitation
Temperature
Radiation
Humidity
PAR
Wind
Ground Heat Flux
Soil moisture
Surface Heat Flux
Evapotranspiration
Sapflow
Runoff plots
Weirs-runoff
…

# Instrumentation

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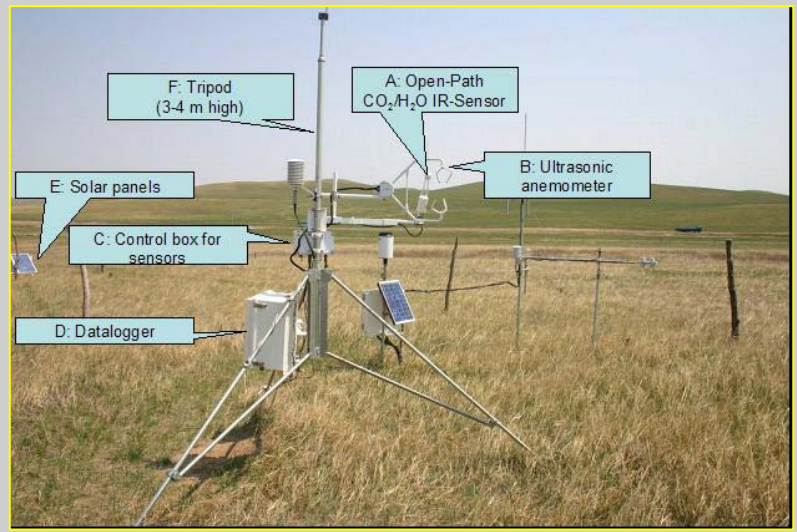
Total & photo-synthetically active radiation

Weir for Runoff Measurement



Scintillometer: heat flux




Automated Weather Station

# Model Integration, DSS

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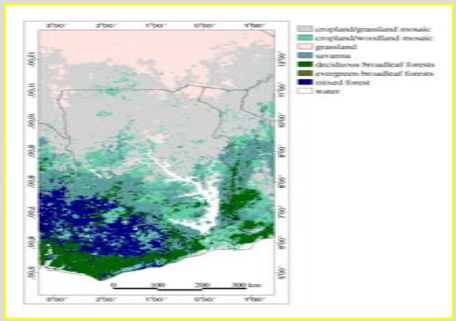

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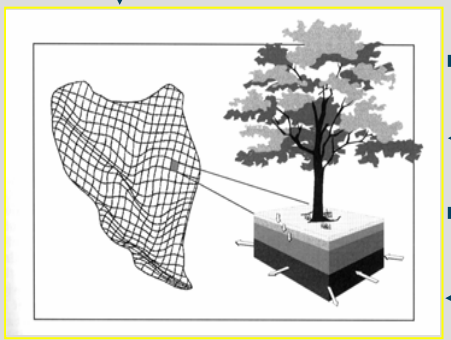
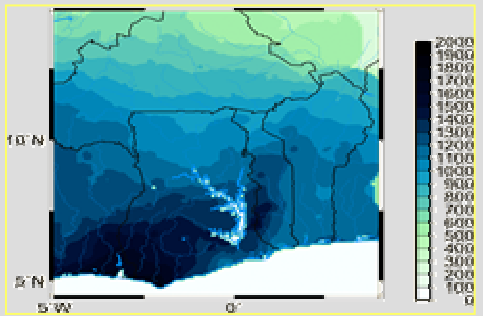


Hydrology



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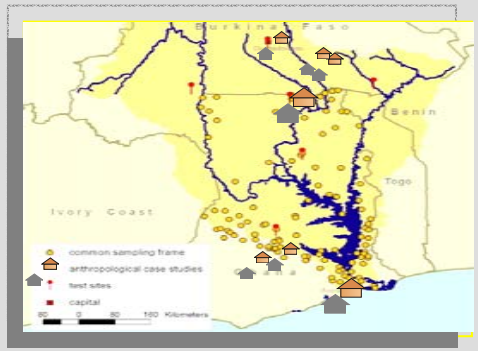
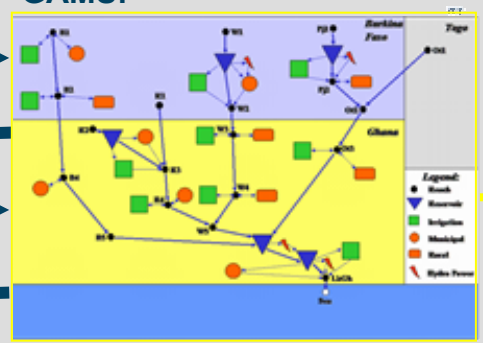


GAMS:



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# Field Research Sites

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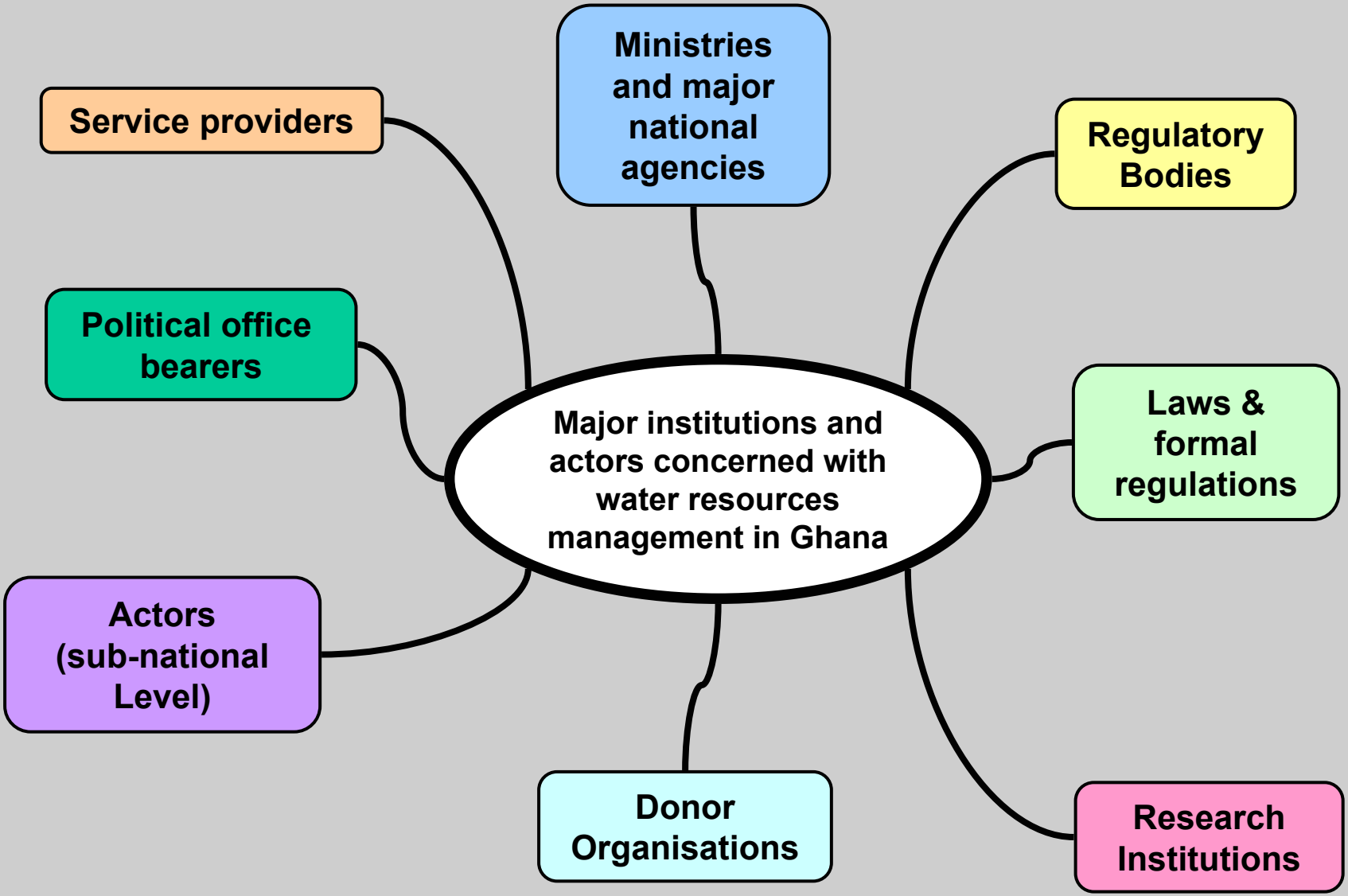
# Institutional Analysis

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# Institutional Analysis

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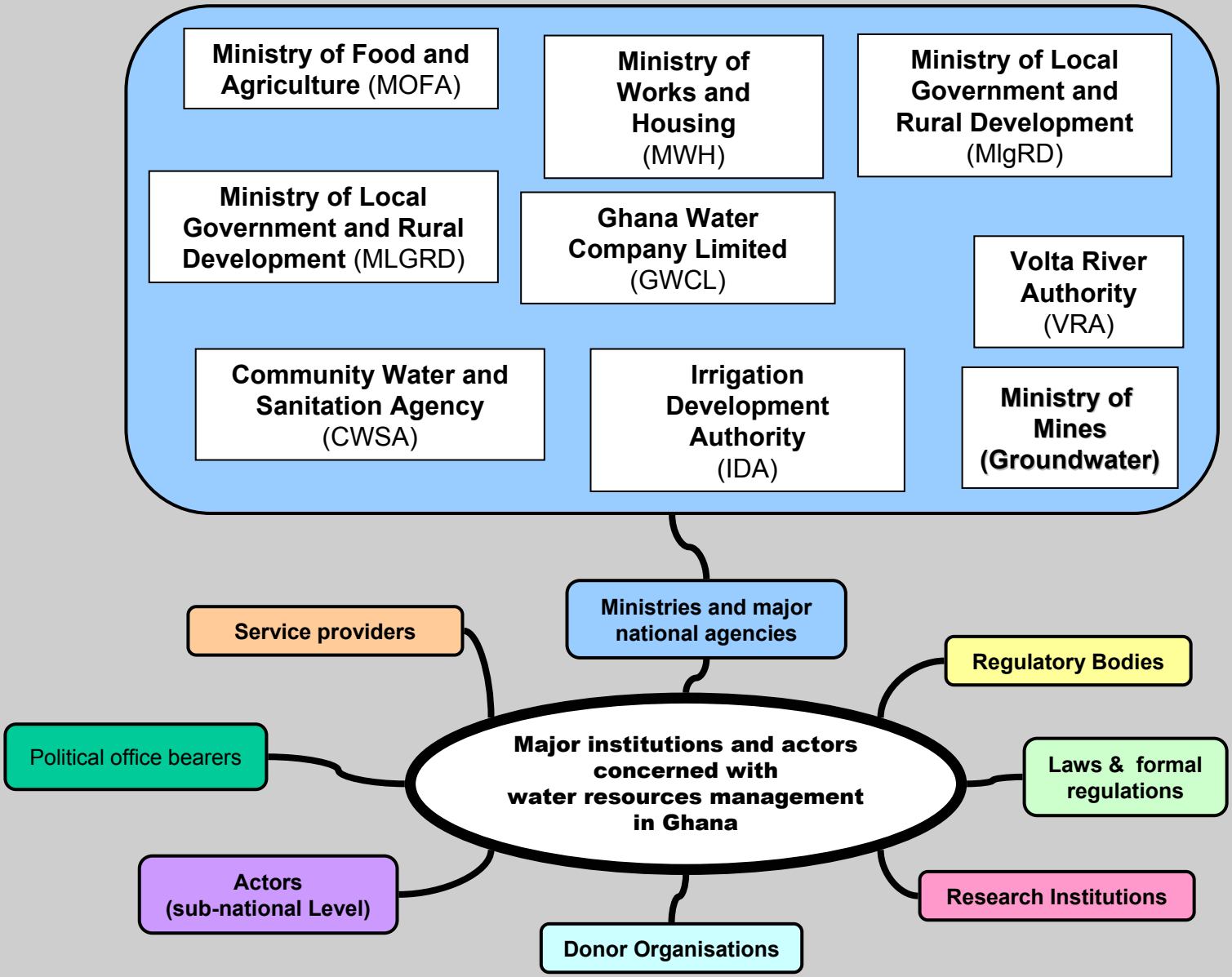

# Institutional Analysis of Irrigation Systems

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## Characteristics of the Institutional Set-up

| Institutional characteristics: | Medium Scale Project | Small Scale Project | Riverine Irrigation |
|---|---|---|---|
| Multiple Institutions | + + + | + + | + |
| Overlapping Responsibilities | + + + | + + | + |
| Conflict of Interest | + + + | + | + |
| Rent Seeking / Nepotism | + + + | + | + |
| Degree of Legitimacy | + | + + | + + + |
| Enforceability of Rules | + | + | + + |
| Consequences: | | | |
| Deviant Behaviour | + + + | + | + |
| Unequalities | + + + | + | + |
| Inefficient Resource Use | + + + | + | |
| Environmental Sustainabilty | + + | + + | ? |
| Conflict | + + | + | |

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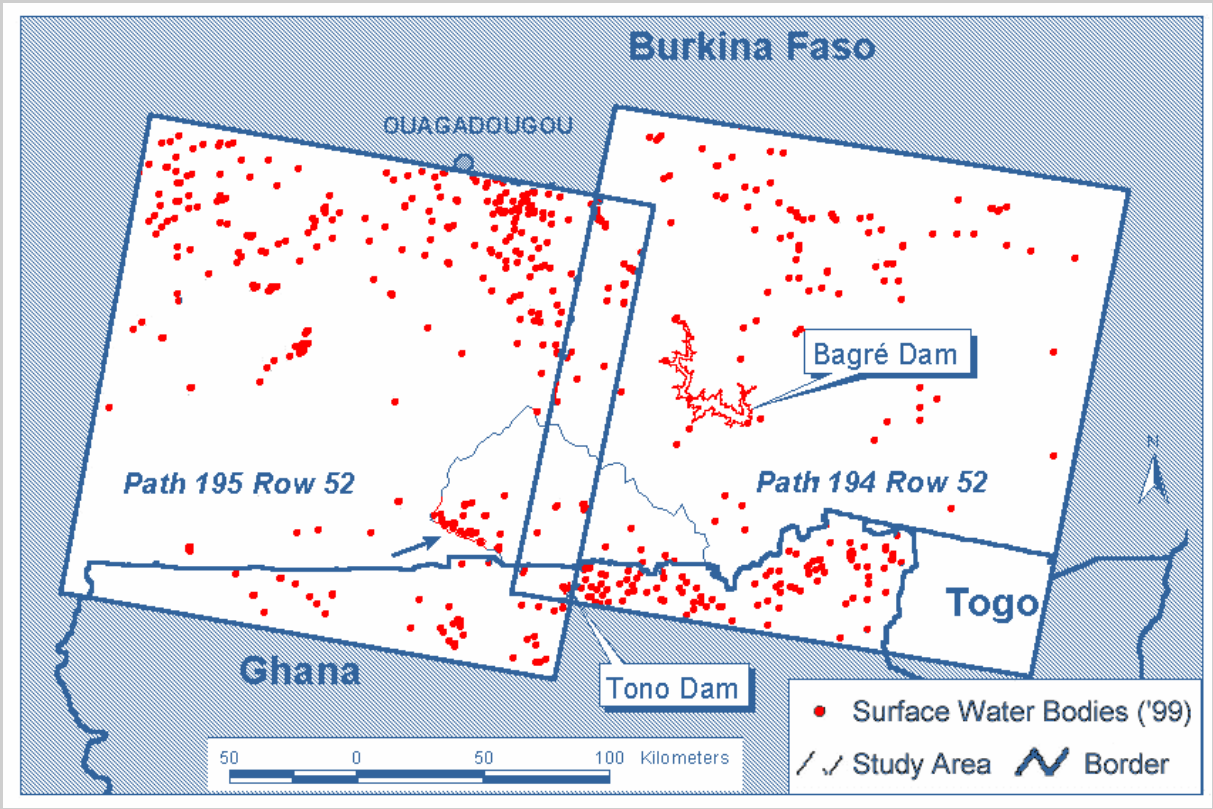
## Growth in Irrigation Water Demand




| | 1984 | 1999 |
|---|---|---|
| # Dams | 302 | 710 |
| ha Reservoirs | 4134 | 31200 |

# Field Research Sites

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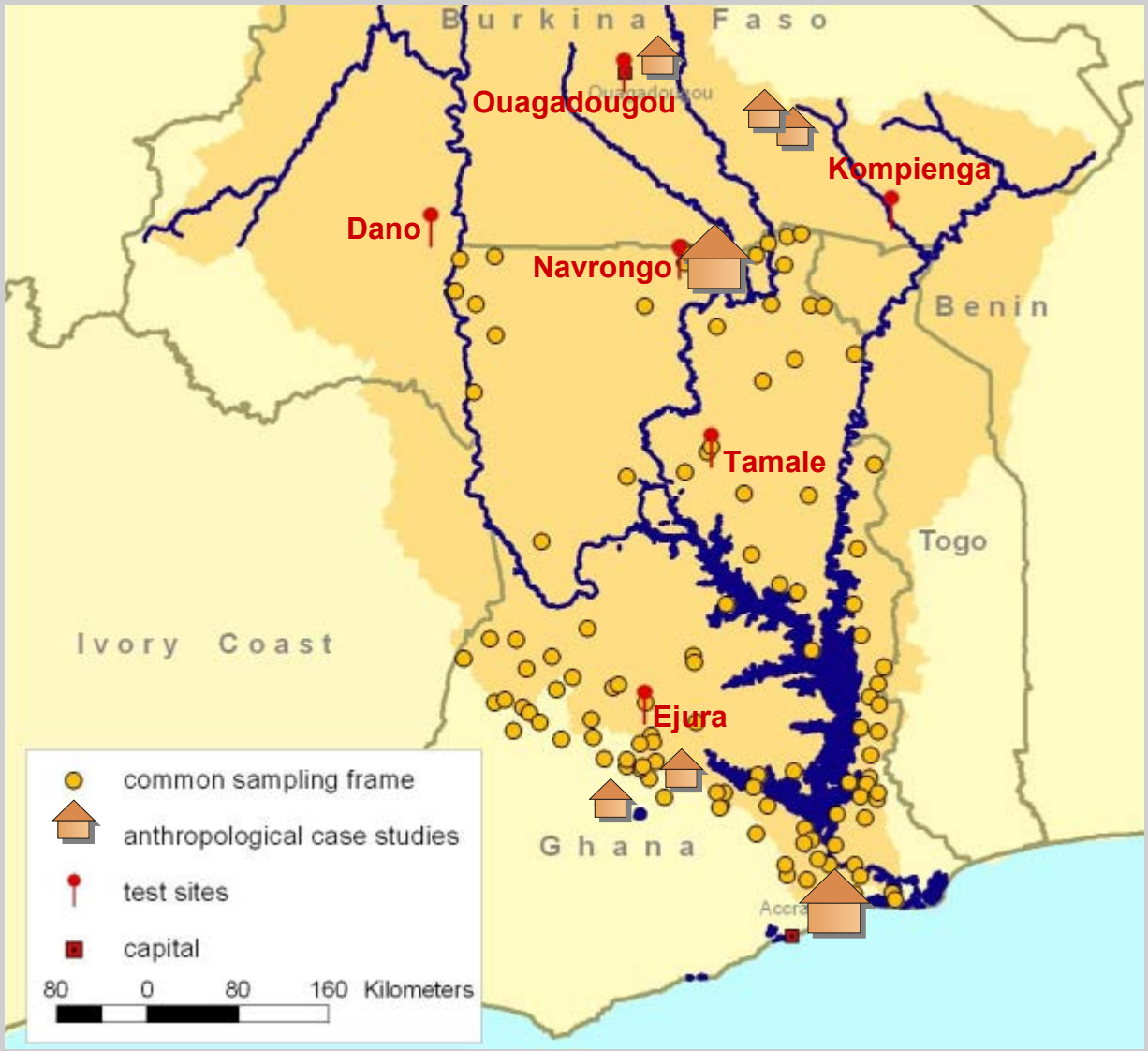
GLOWA Volta

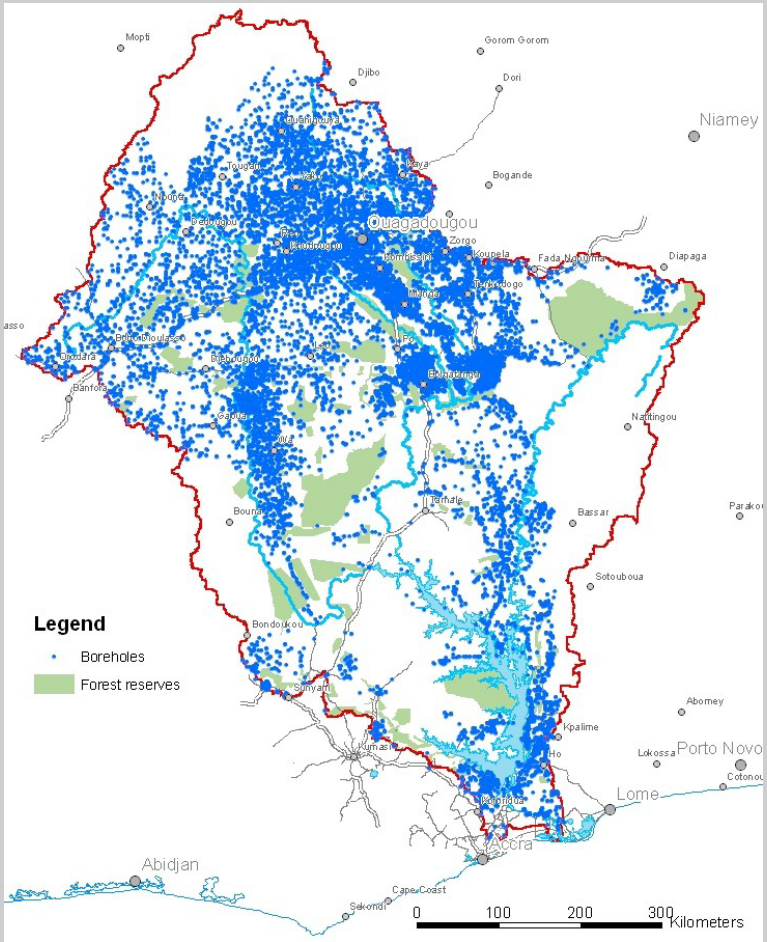


# Water and Livelihood

ZEF

GLOWA Volta

## Household water use



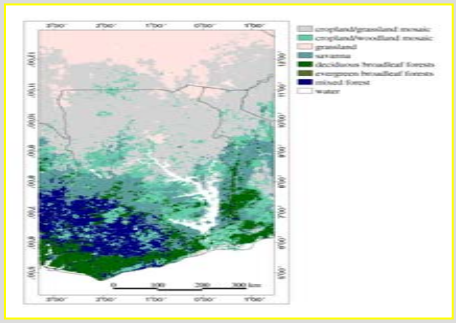

- Ghana Living Standards Survey
- Structured Sample Surveys
- All boreholes mapped
- Community interviews
- Water sampling
- Soil Sampling

# Model Integration, DSS

ZEF

GLOWA Volta

## Climate, Land Use, Hydrology

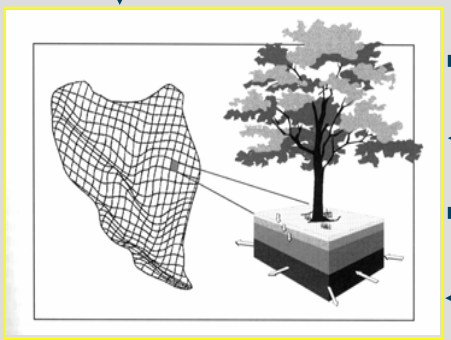


LUDAS: Land Conversion

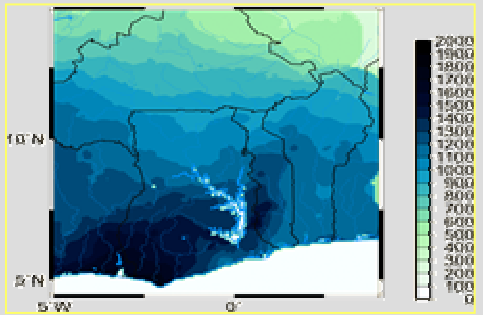
Remote Sensing

Instrumentation

WaSIM:



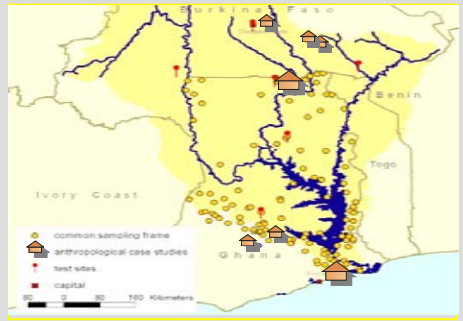
Hydrology



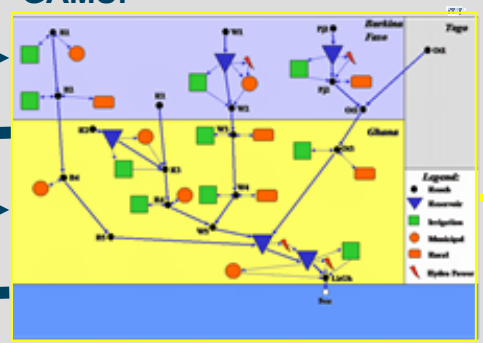

MM5: Mesoscale Climate

## Economics, Institutions, Stakeholders

Field Sur-veys




GAMS:



Integrated Basin Model


Institutional Analysis

Decision Support System

Ministers

WRC

Water Board

WATSAN

DA

VRA

Donors

# Integrated River Basin Modeling

ZEF

GLOWA Volta

- River Basin as the unit of analysis
- Unified consideration of physical, social dimensions of water management

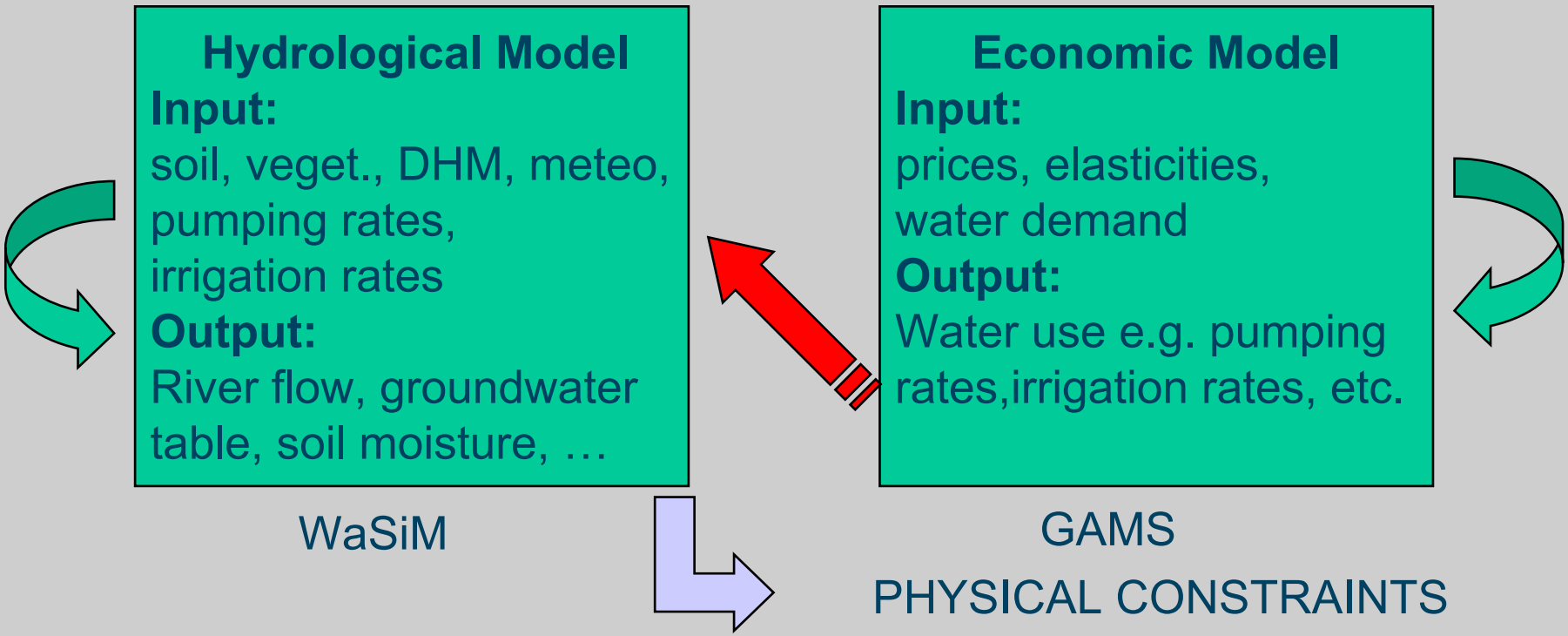
- Optimize economic/allocative water efficiency subject to:
- Constraints posed by climate, hydrology, infrastructure, environment (WQ), laws, institutions, custom, ...

GLOWA Volta

## Information Exchange

Physical surface & subsurface water balance

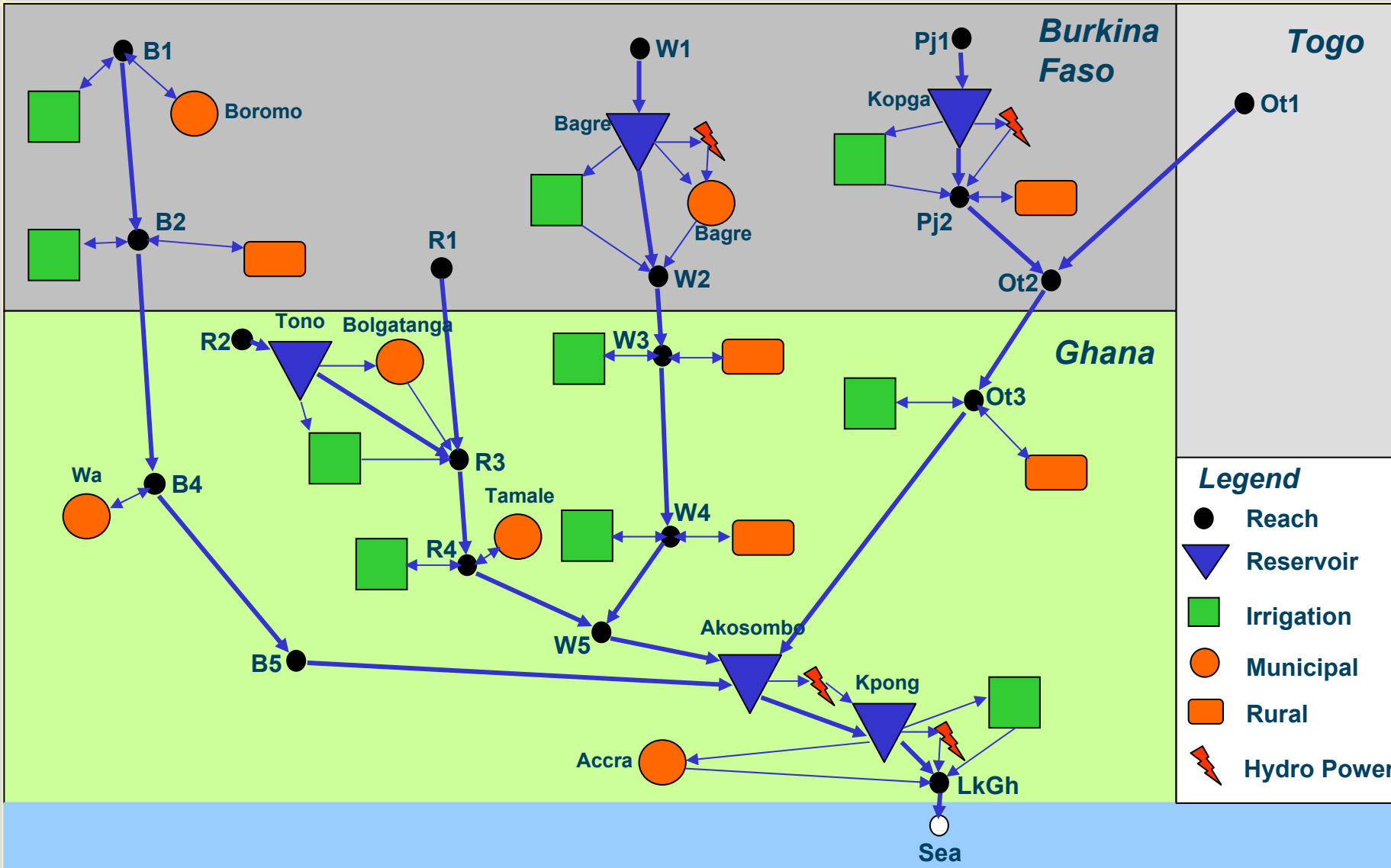
Water use and/or optimization of water use



# Schematic, Volta Integrated Hydrosystem

ZEF

GLOWA Volta

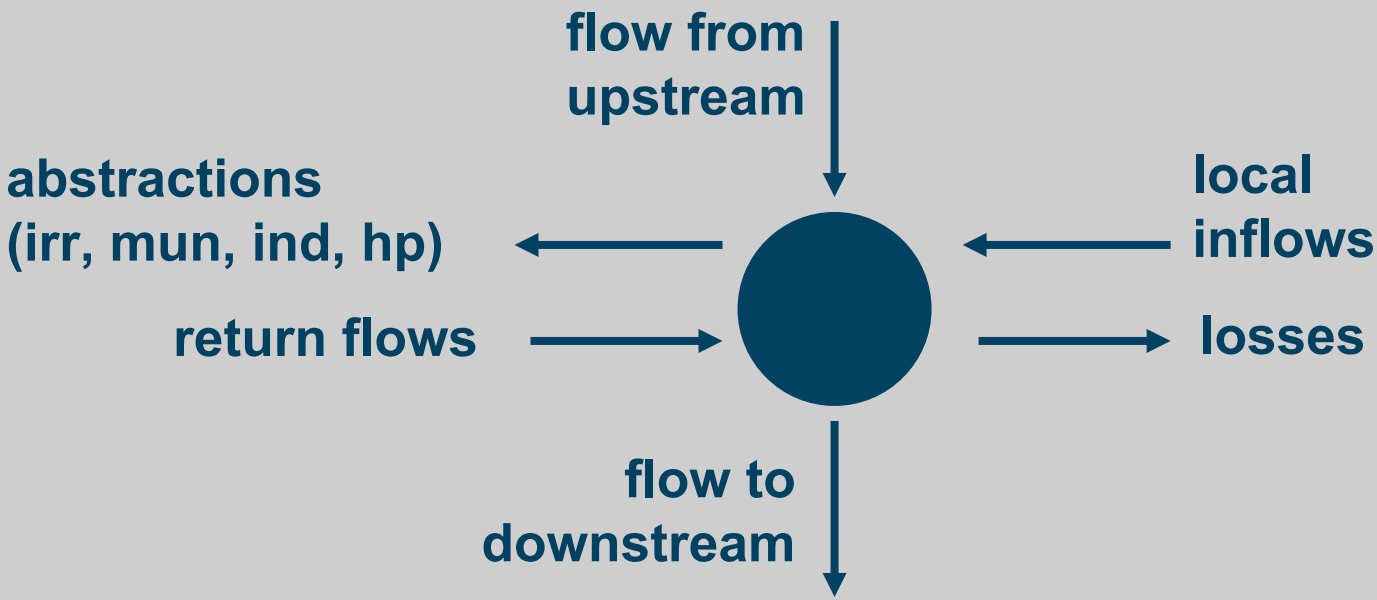


# Network Mass Balance

ZEF

GLOWA Volta

$$\sum Q_{in} + I_i + \sum R = \sum Q_{out} + \sum A + \sum L + \Delta S$$



# Unified Economic Objective Function

ZEF

GLOWA Volta

$$Z = \{\sum_{ir} \sum_{c} \sum_{tp} cval_{ir,c,tp} + \sum_{hr} \sum_{t} P\_hpr_{hr,t} + \sum_{hp} \sum_{t} P\_hpd_{hp,t}$$

$$+ \sum_{mu} muval_{mu} + \sum_{id} \frac{indval_{id}}{1000} - \sum_{r} penalty_{r} \}$$

Z = total net value of water-supported economic activity

cval = value of irrigated agriculture

P_hpr = value of hydropower, reservoir

P_hpd = value of hydropower, run-of-river

muval = value (cs) of municipal (domestic) use

indval = value of industrial use

penalty = reservoir overdrought penalty

Subject to: environmental flow restrictions, water rights, interstate compacts, …

# Model Integration, DSS

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GLOWA Volta

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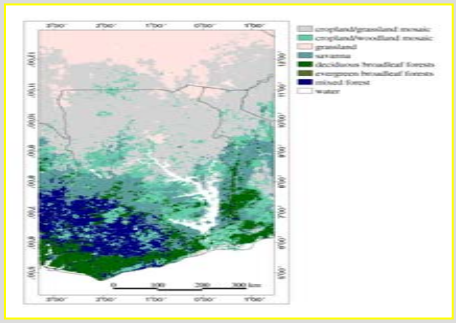

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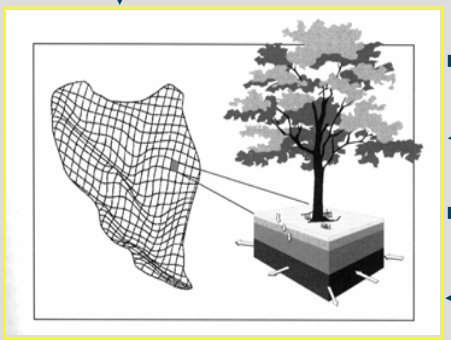

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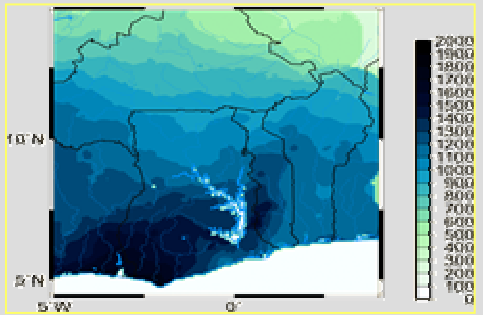


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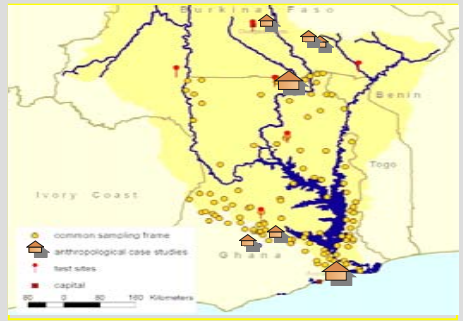
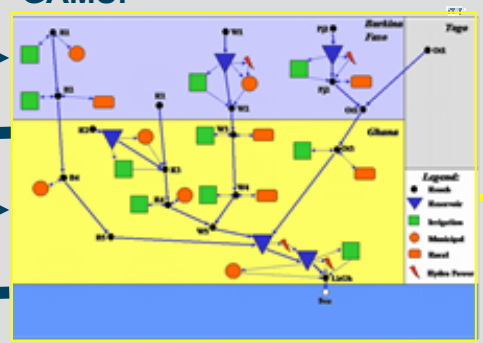



GAMS:



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# Research Network

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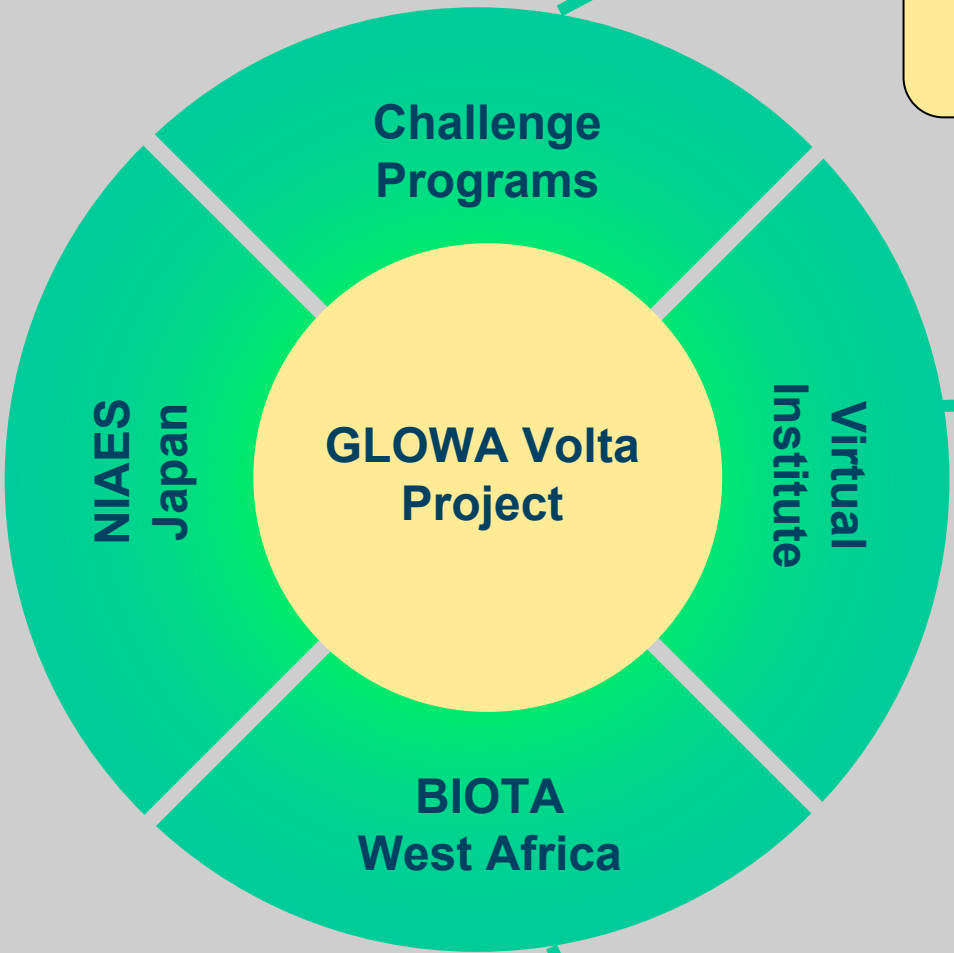


Small Reservoirs
Governance & Modeling
Nutrient Cycling

Dreyer Foundation
IFU
ZEF
Kiel

Biophysical, hydrometeorological parameters of terrestrial biodiversity

# Acknowledgement

ZEF

GLOWA Volta

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IWMI International Water Management Institute

Bundesministerium für Bildung und Forschung bmb+f

IFU

dreyer stiftung

NRW.

INERA

SARI

CGIAR Challenge Program on WATER & FOOD

CSIR Water Research Institute

DLR