Vulnerability of the Pra River Basin to water stress under future development (population growth and climate change)

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1st August, 2012

Background

- **Climate Change in Africa and Ghana**

– IPCC climate forecast for Africa indicates:

  - warmer and wetter
  - dryer with frequent extreme events of flood and drought

– Ghana:

  - Steady rise in temperature (GMA data: 1961-1990)
  - 30 year absolute increase of 1°C
  - Impact on hydrologic cycle and water resources

– Climate Change comes with enormous challenges

  - Nationally set targets of sustainable development
  - Millennium Development Goals (MDGs)

Background - 2

- **Measures to deal with climate change**

– Mitigation (reducing sources and increasing sinks)

  - Reducing CO_2 emissions

– Adaptation (adjusting human and natural systems to moderate harm)

  - Focus of this steady

➢ Designing adaptation measures require an understanding of the impacts of climate change on water resources

Objectives

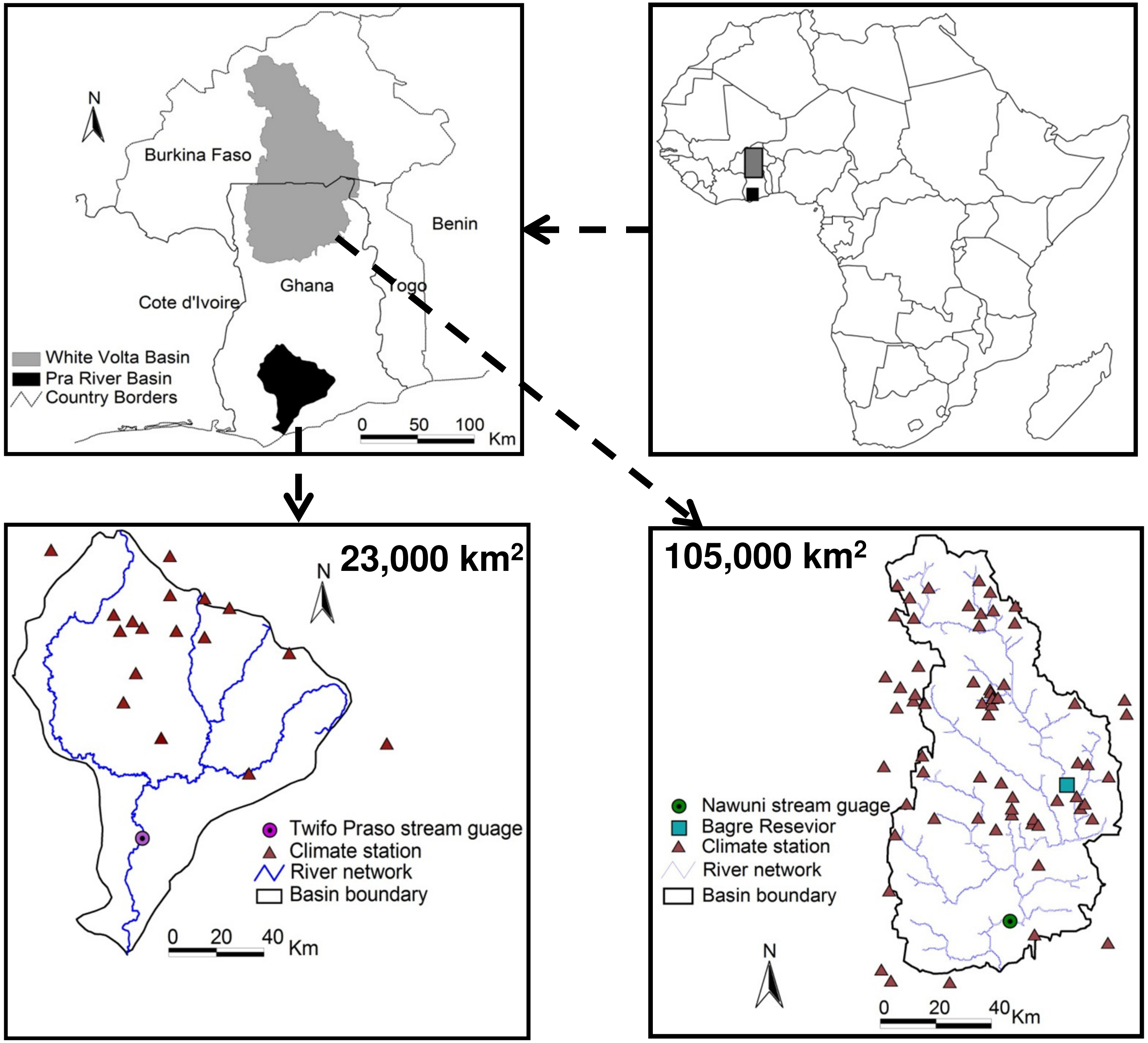
- **Overall Objective**

  - To generate scientifically sound impact-specific information that can be used to directly inform preparation of local and national adaptation measures on climate change in the water sector in Ghana

- **Specific objectives**

  - Estimate the impact of climate change on streamflow; and
  - Assess vulnerability of the study basin to water stress conditions
  - Recommend adaptation measures for sustainable management of the water resources

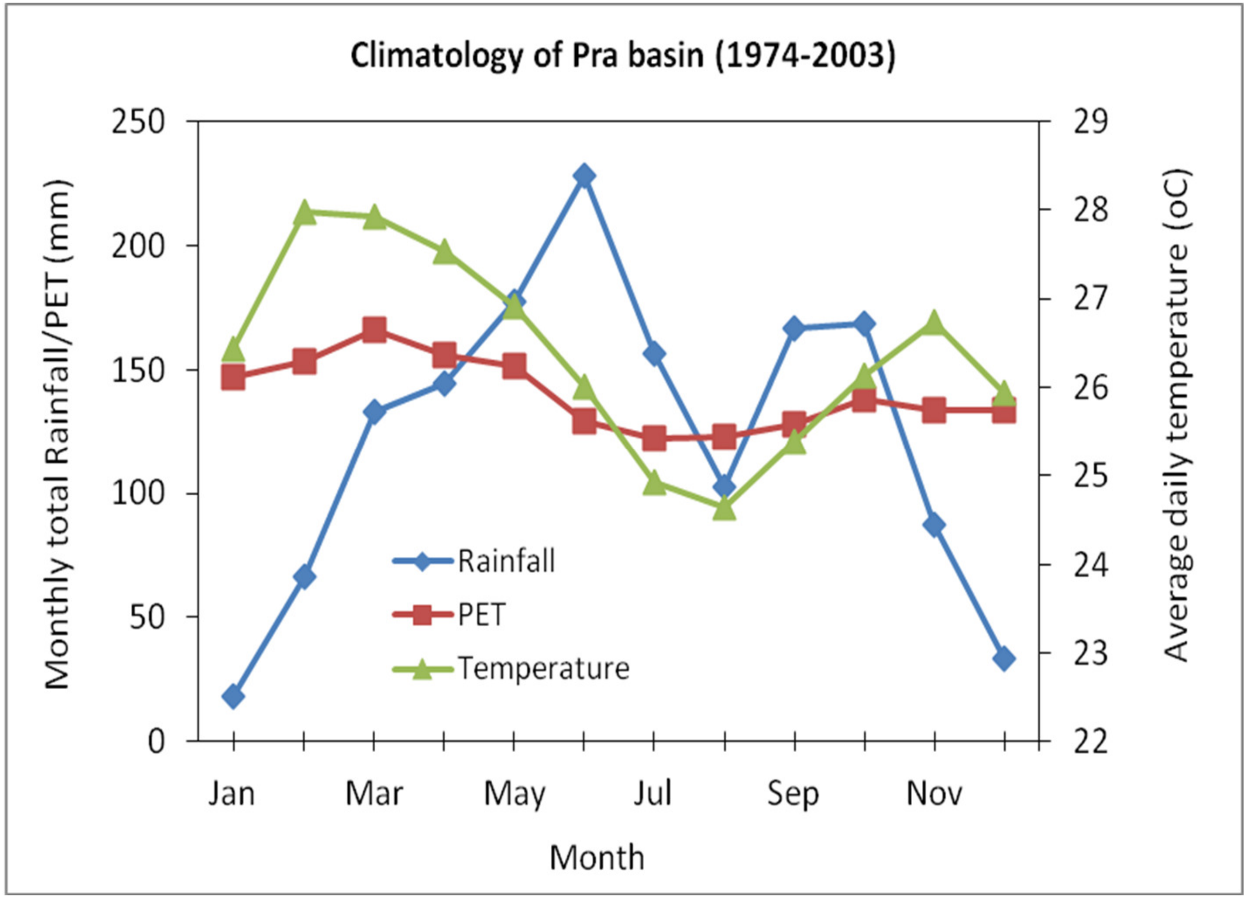
River Basins



PRA

WHITE VOLTA

Climatology of Pra Basin

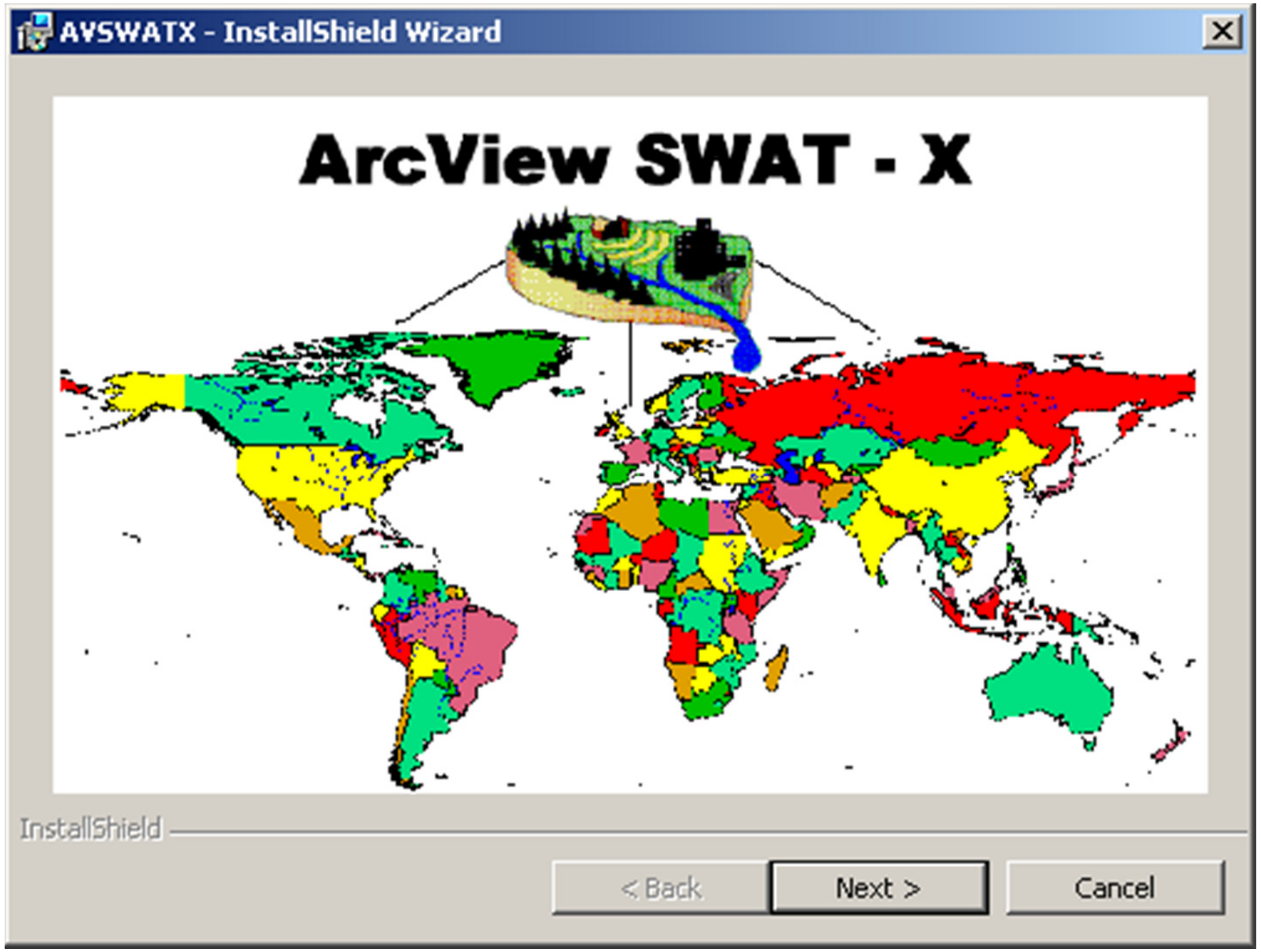


Climatology of the Pra Basin (Data source: GMA)

Mean climate values	
Annual rainfall (mm)	1500 - 2000
PET (mm)	1650
Daily tempt (°C)	25 - 28

Method and Data

- **Hydrologic Modeling with SWAT (Neitsch et al., 2005)**

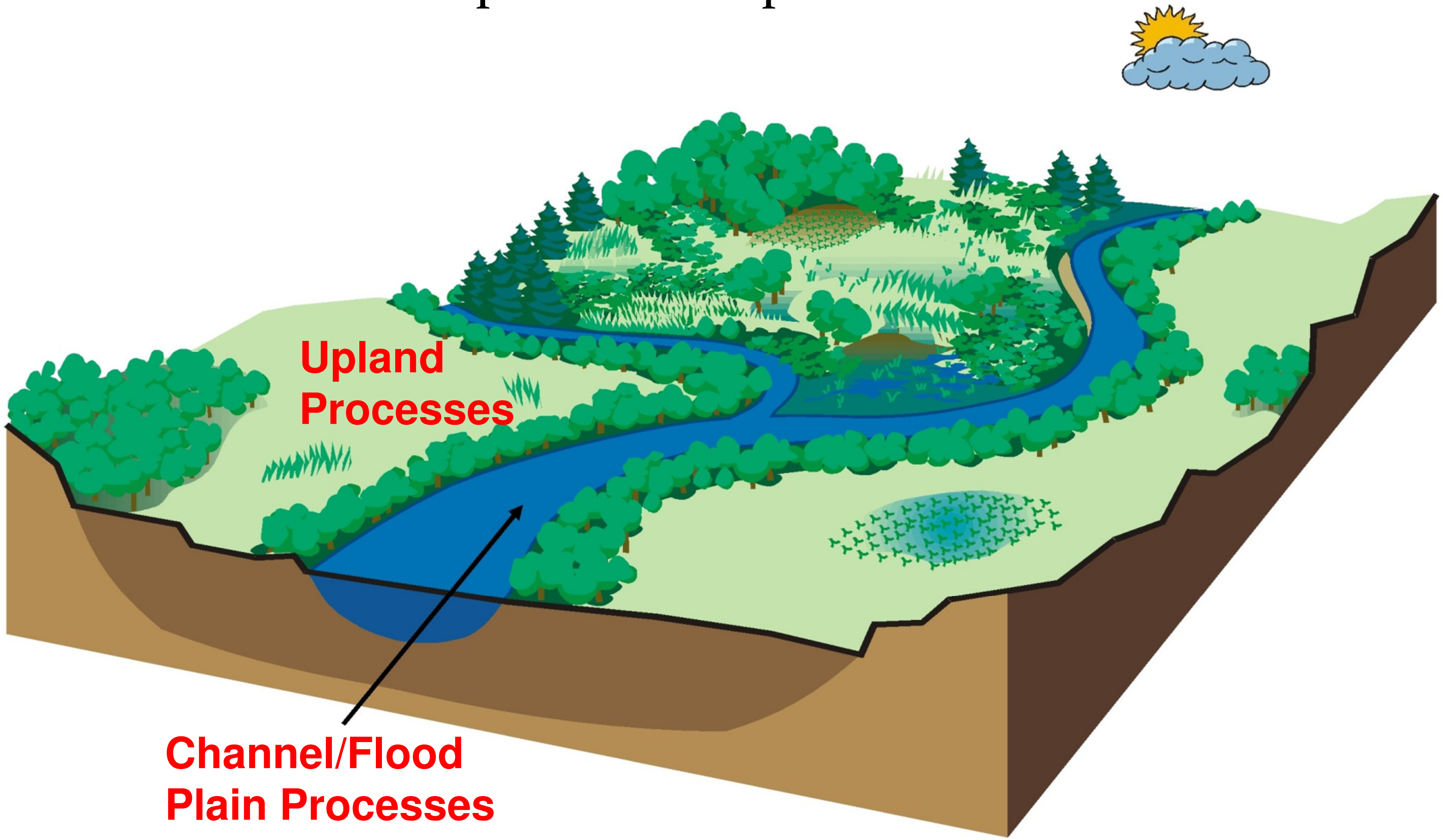


Method and Data - 2

- **Model Description**
  - Semi-distributed model
  - Uses a GIS interface
  - Readily available inputs data
  - Computationally efficient
  - Wide use

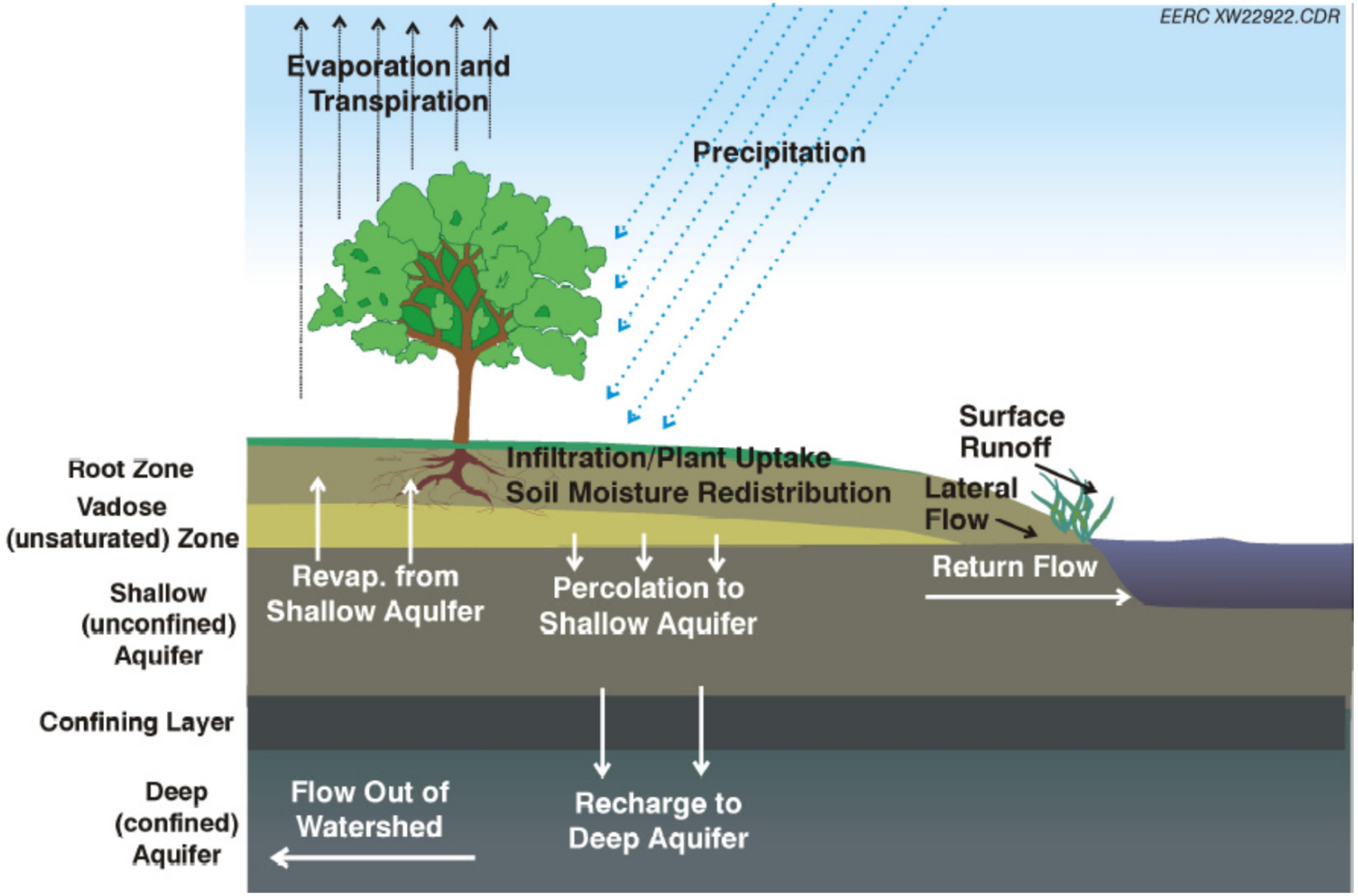
Method and Data - 3

- **SWAT Watershed system**
  - Simulates 2 main processes: Upland and Channel



Method and Data - 5

SWAT Hydrologic cycle



SWAT hydrologic cycle (EERC-University of North Dakota, 2008, modified from Neitsch et al., 2005)

Method and Data - 6

SWAT water balance equation (Neitsch et al., 2005):

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right)$$

where SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

Method and Data - 7

SWAT key input data

- Digital elevation model
- Soil map and data (e.g., BD, SHC, AWC, ST, OC, etc)
- Land use map and data (e.g., LAI, PHU, etc)
- Climate data (e.g., P, Tmax, Tmin, RH, SR or SSH, WS)
- Streamflow data

Method and Data - 8

➢ SWAT calibration and validation:

Calibration	1964 - 1978
Validation	1971 - 1994

➢ SWAT performance evaluation:

– Nash-Sutcliffe model efficiency coefficient (NSE)

– Coefficient of determination (R^2)

– Percent Bais (PBAIS)

Methods - 3

- **Climate change scenario:**
  - GCM: ECHAM4
  - IPCC "SRE" Scenario: A1B
  - Downscaling: Stochastic weather generator LARS-WG
  - Simulation periods:
    - Baseline:1961-1990
    - Future time slices: 2006-2035 (scenario 2020); 2036-2065 (scenario 2050)

Method - 4

- **Water Stress Condition (WSC):**

  - Falkenmark indicator/water stress index (Falkenmark et al., 1989)

    – Water Stress: 1700 cm^3/person/year

    – Water Scarcity: 1000 cm^3/person/year

    – Absolute Water Scarcity: 500 cm^3/person/year

  - Assessment periods

    – Baseline: 1964-1994

    – Future time slice 1: 2006-2035 (Scenario 2020)

    – Future time slice 2: 2036-2065 (Scenario 2050)

Method - 5

- Under each time scenario, the WSC was assessed considering
  - Population growth only (Without Climate Change)
  - Population growth + Climate Change (With Climate Change)

- Mobilization assumptions
  - 100% mobilization
  - 30% mobilization(due to constraints)

Results

- **SWAT Calibration and validation**

Simulation type	Period	Monthly R^2	Monthly NSE	Daily R^2	Daily NSE
Calibration	1964-1978	0.90	0.88	0.82	0.84
Validation	1979-1994	0.88	0.86	0.80	0.79

Minimum requirement for successful calibration of SWAT: NSE > 0.50; R^2 > 0.60; PBAIS $\pm$25% (Moriasi *et al.* 2007; Santhi *et al*. 2001)

Results - 2

- **Climate change impact on streamflow**

➢ Temperature and rainfall projections

Scenario	Temperature (°C)	Rainfall* (mm)
Baseline (1961-1990)	**26.4**	**1450.0**
2020 (2006-2035)	**26.9**	**1191.6**
Change	**+ 0.5**	**-17 %**
2050 (2036-2065)	**28.3**	**1074.2**
Change	**+ 1.9**	**-26 %**

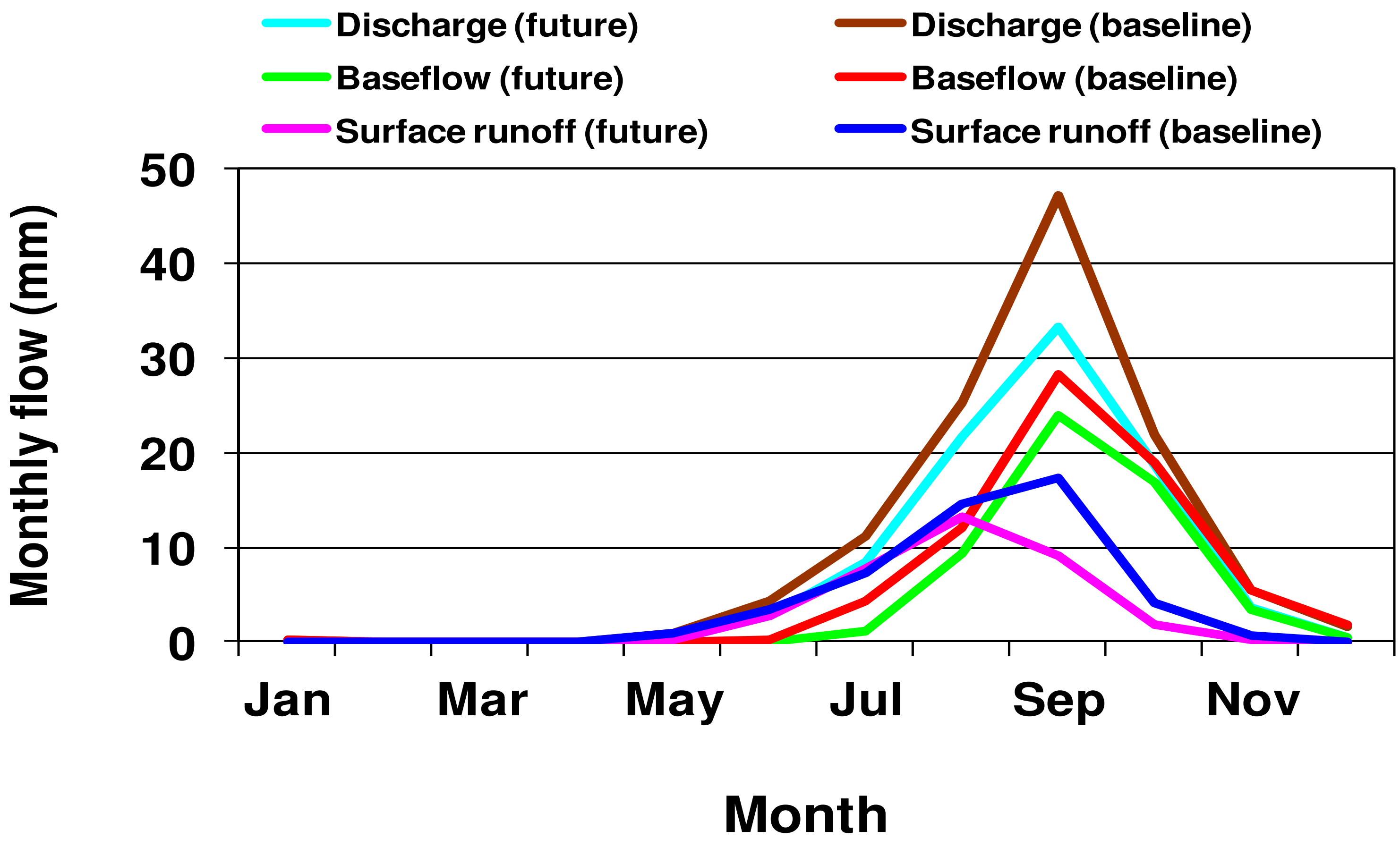
Results - 3

- **Climate change impact on streamflow**
  - Changes in mean annual streamflow

Scenario	Streamflow (mm)
Baseline (1961-1990)	**226.1**
2020s (2006-2035)	**175.8**
Change (%)	**-22**
2050s (2036-2065)	**121.5**
Change (%)	**-46**

Results - 4

- **Climate change impact on streamflow**
  - Changes in mean monthly flow



Results - 5

- **Vulnerability to water stress**

– Population projections for Pra basin

Annual growth rate (%)	1990	2020	2050
2.7	4,034,713	6, 874,190	15,287,442

– Annual streamflow in Pra basin under baseline and climate change

Mean annual streamflow in million m^3		
Baseline (1964-1994)	2020	2050
5,200	4,043	2,795

Results - 6

- **Vulnerability to water stress**

– Dynamics of water availability (m^3/person/year) in the Pra Basin with and without climate change

Year	No climate change		Climate change	
	100%	30%	100%	30%
baseline	1288.9	386.7	1288.9	386.7
2020	756.4	226.9	588.2	176.5
2050	340.2	102.1	182.2	54.8

Water stress (Green):1700 m3/p/year; Water scarcity (Yellow):1000 m3/p/year; Absolute scarcity (Red): 500 m3/p/year

Conclusions

- SWAT is able to adequately simulate the streamflow of the White Volta and Pra River Basins
- Estimated mean annual streamflows for the 2020 and 2050 scenarios show important decreases over the baseline
- Without climate change, the Pra basin is already water stressed and projected to attain water scarcity condition by 2020
- Climate change will worsen the water stress condition in the basin

Recommendations

- ## Recommendation

- Adoption and implementation of integrated water resources management (IWRM) with emphasis on water use efficiency, water conservation, environmental integrity
- Investing in appropriate cost-effective adaptive land and water management practices
- Groundwater could be developed and used as adaptation strategy to reduce the vulnerability of the basin inhabitants.
- Population growth needs to be checked via (i) promotion and accessibility to family planning services, (ii) Female education and empowerment

Thank You