# Watershed model applications
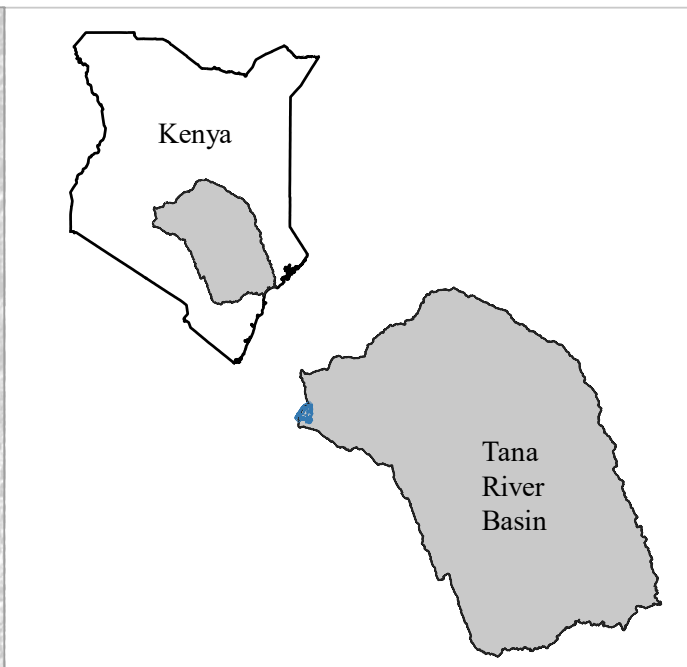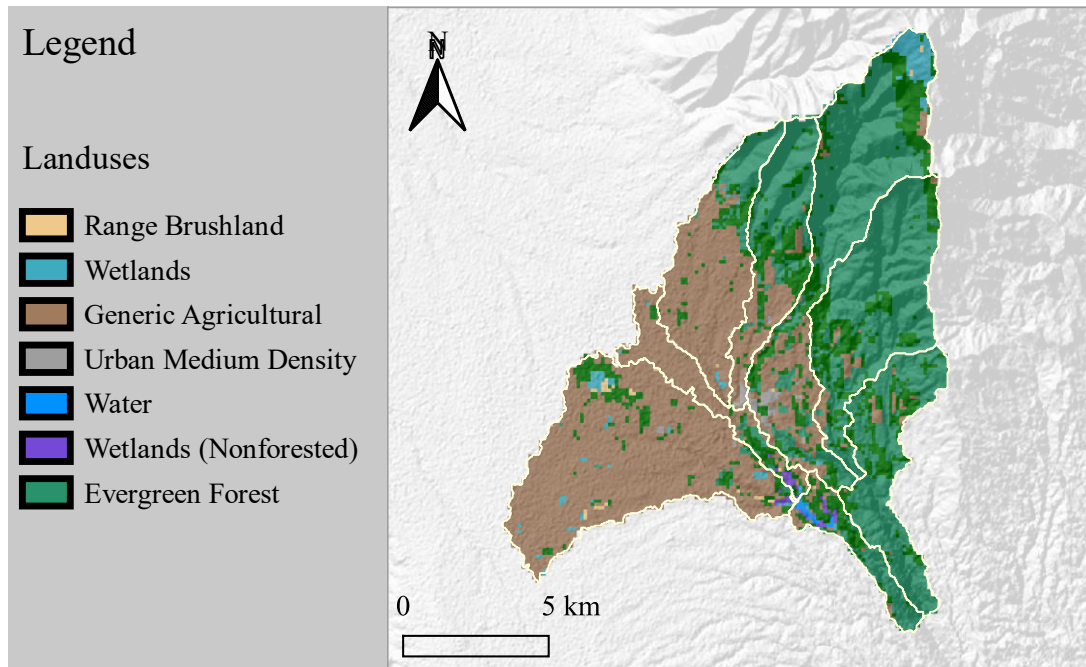
Workshop 05/09/2022

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# 3- Watersheds: Sasumua - Kenya



Legend

Landuses

- Range Brushland
- Wetlands
- Generic Agricultural
- Urban Medium Density
- Water
- Wetlands (Nonforested)
- Evergreen Forest

Kenya

Tana River Basin

Size: ~136km$^2$

Watershed is located within the Tana River Basin

Aqueduct connects Chania River to Sasumua River 5km upstream of dam, and water is diverted from Kiburu River to reservoir

Primary landcover transitions from agriculture to forest as elevation increases

# 3- Watersheds: Simiyu - Tanzania
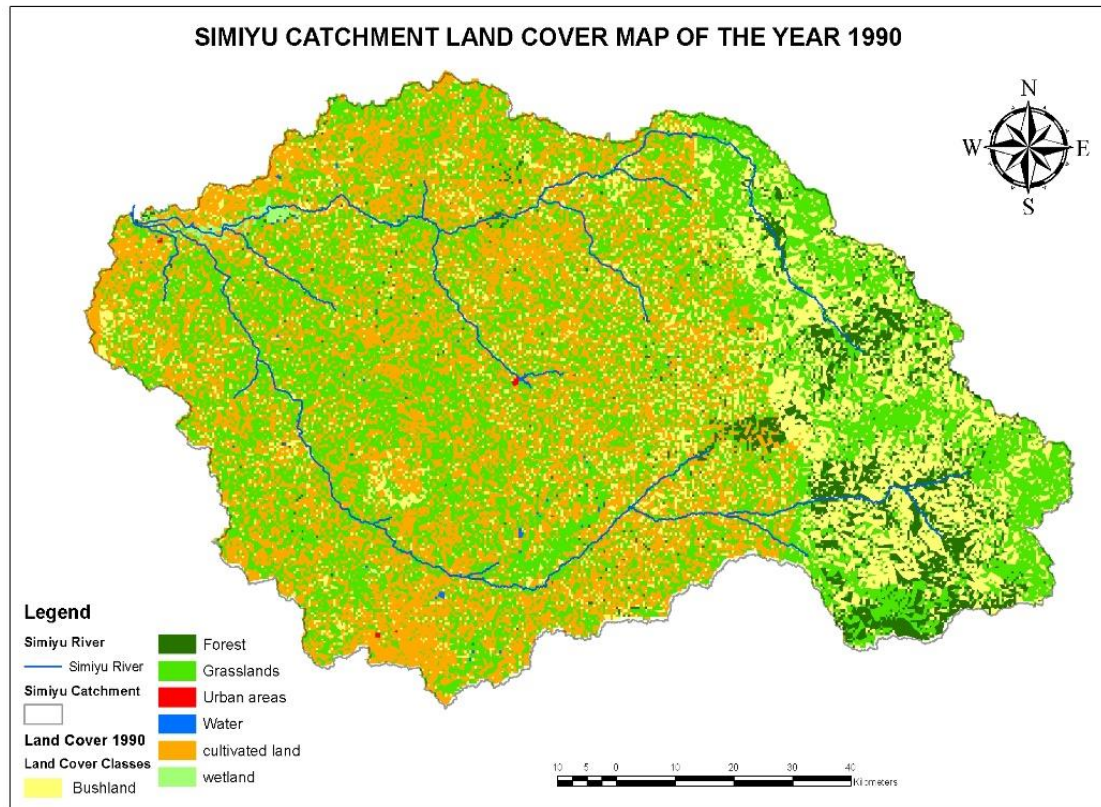


Simiyu River catchment Drains its water into the Lake Victoria

Total Area
~10,659 km$^2$

The River Simiyu is ephemeral and contains water during and immediately after a storm event only

The water towers of the Simiyu are from the Serengeti National Park (SNP) and the Maswa Game Reserve - famous touristic attractions in the world

# 3- Watersheds: Murchison Bay - Uganda

The catchment delivers water from Kampala city through Nakivubbo channel to Lake Victoria
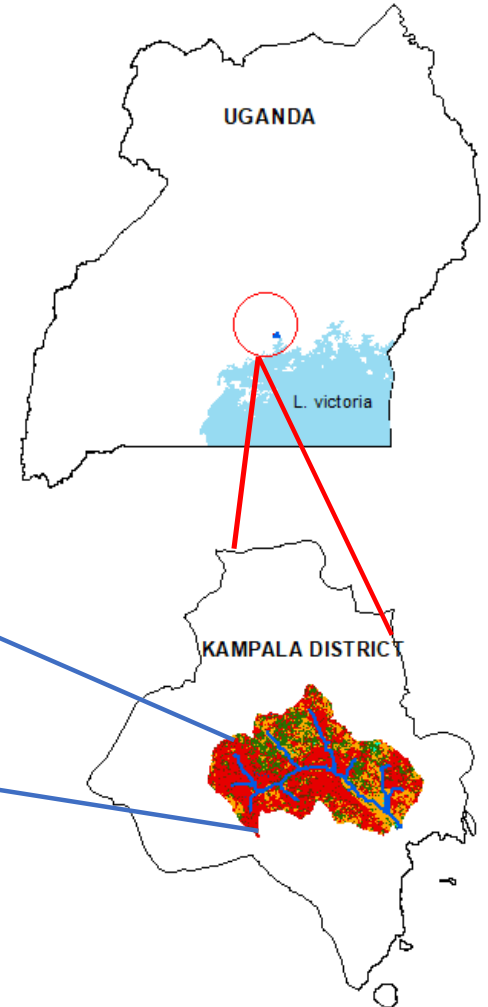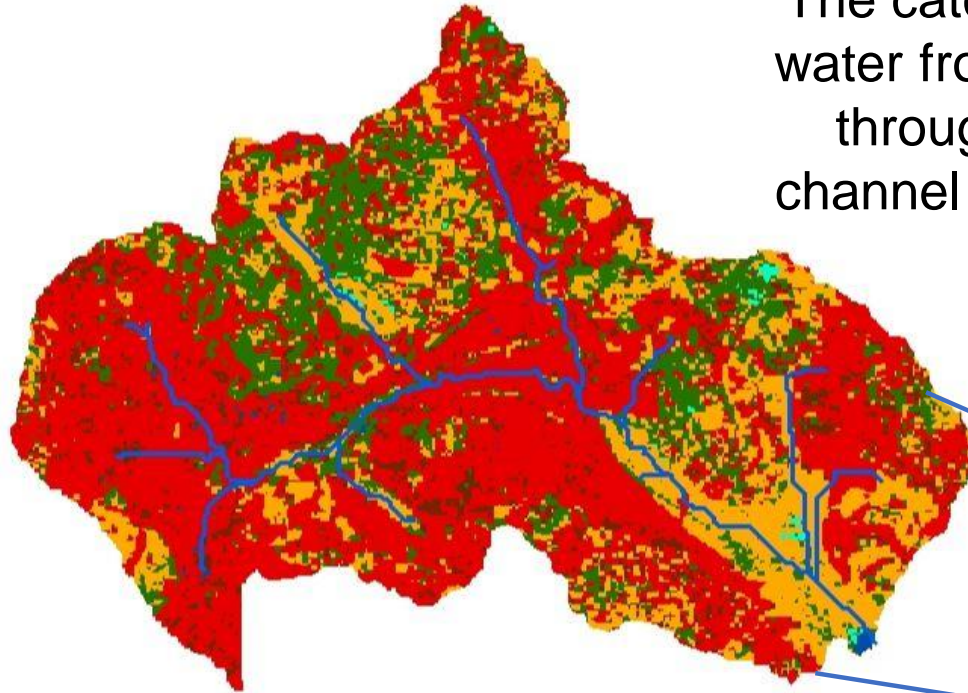


**KEY**

—— Nakivubbo_Channel

**Land_use_2020**
**Class_Name**

AgriculturalLand  (21.68 %)
Bareland          (7.65 %)
Builtupland       (52.78 %)
Forestland        (17.32 %)
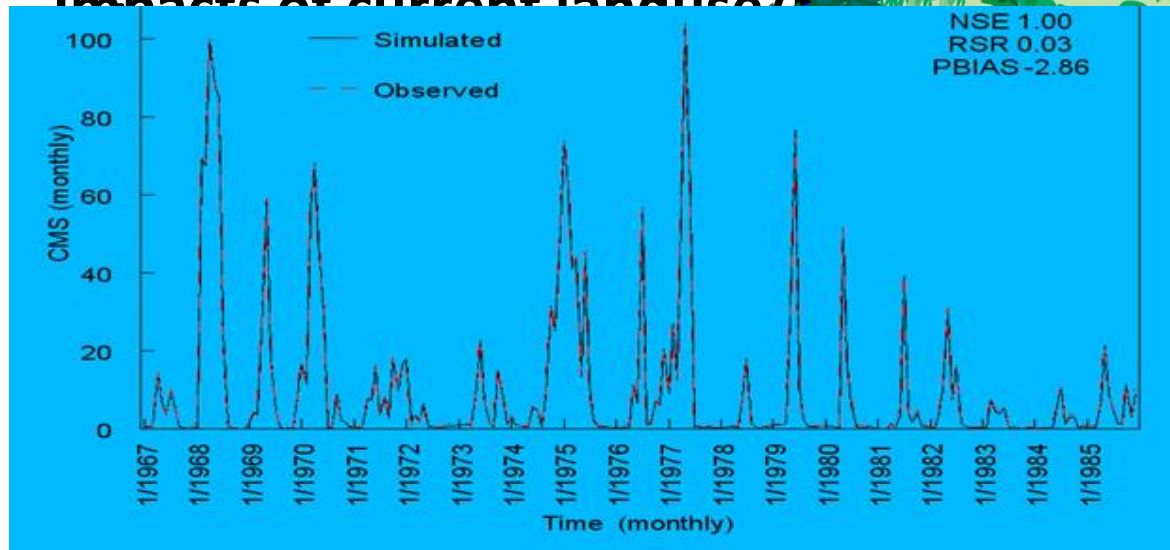Waterbody         (0.25 %)
Wetland           (0.32 %)

Size: ~40 km²

Kilometers
0 0.5 1    2    3    4

# Modeling Approach

- **Model parameter adjustment** + **model outputs vs. measurements**
  - **Constrain with** available measurements and published literature
    - Statistical measures – NSE, $R^2$, RSR, PBIAS, etc.
    - Graphical

- **Define and perform modeling scenarios**
  - Impacts of current landuse/...



NSE 1.00
RSR 0.03
PBIAS -2.86

Simulated
Observed

CMS (monthly)

Time (monthly)

Soil and Water
Assessment Tool

...s.edu/swat

Channel/Flood Plain
Processes

5

# Sasumua: Problem Statement

- Upstream catchment where agricultural activities have encroached on natural catchment for the dam

- Land fragmentation with intensive agriculture and use of inputs likely to pollute water resources

- Urban centres which have sprang up after the Sasumua dam was built. These are rapidly growing with threat of pollution of water resources

- Water abstraction for Nairobi city amid shortages for rural people (mostly shortage of irrigation water)

- Climate change threats and their impact on water resources not adequately quantified.

# Sasumua: Problem Statement

- Sasumua is an upstream watershed and provides a substantial amount of fresh water to Nairobi. Keeping water quality high is important to downstream interests.

- Agricultural land is slowly beginning to encroach on forested areas of the watershed.

- There is little information on what impacts the changing climate will have on Sasumua Watershed.

# Sasumua: Case Study Objectives

**Overall Objective:** Demonstrate data use for data-driven decision-making with respect to water resources management

**Specific Objectives**
1. Develop a SWAT + model for the Sasumua River Watershed.

2. Predict the effects of implementing a variety of management practices on sediment and nutrient losses.

3. Form an impression of how projected changes in climate will affect the watershed.

# Sasumua: Validation of model outputs

| | ET | Surface Runoff | Sediment |
|---|---|---|---|
| Target | 75% | 14% | < 10 tons/ha |
| Calibration | 43% | 15% | 0.04 tons/ha |
| Validation | 37% | 20% | 0.07 tons/ha |

- Archer, D. (1996) Suspended sediment yields in the Nairobi area of Kenya and environmental controls. In *Erosion and sediment yield: global and regional perspectives. Proceedings of the Exeter Symposium, July 1996*, Eds. Walling, D.E. & Webb, B.W. Vol. 236, 37–48.
- Hunink, J. E., & Droogers, P. (2011). Physiographical baseline survey for the Upper Tana catchment: erosion and sediment yield assessment. Future Water Report, 112, 31. https://futurewater.nl/wp-content/uploads/2013/01/2011_TanaSed_FW-1121.pdf Accessed 7 Jan 2022.
- Mwangi et al.(2015) in *Journal of Soil and Water Conservation*, *70*(2):75–90. https://doi.org/10.2489/jswc.70.2.75

# Sasumua: Scenario Descriptions

Two scenario types were considered in the Sasumua case study:



- Effects of Conservation Measures (6 Scenarios)
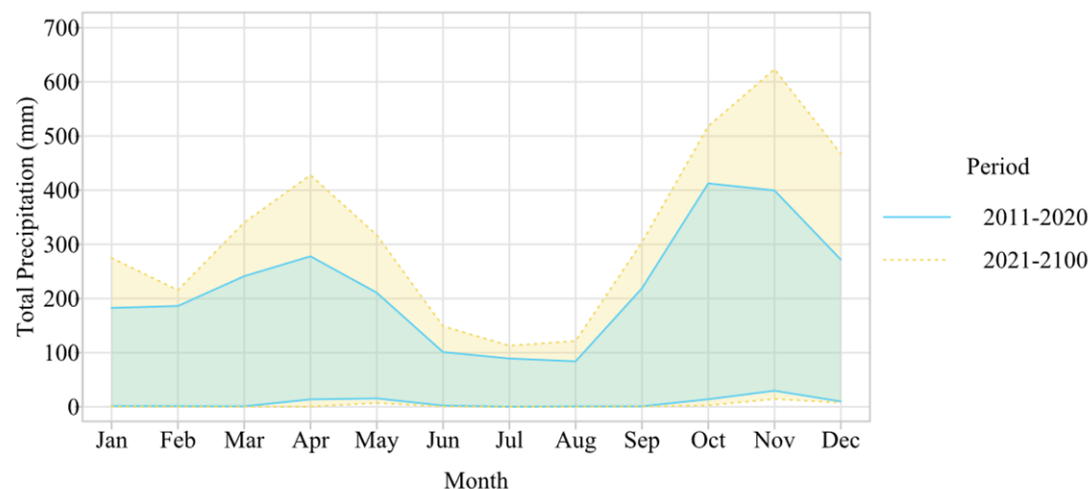


- Effects of Future Climate (4 Scenarios)

# Sasumua: Management Scenario Descriptions

| Management Scenario | Modifications |
|---|---|
| Baseline | Cross slope tillage implemented on agricultural land. |
| 1 Riparian Buffers | Indiscriminate buffer of rangeland around the stream network. |
| 2 Filter Strips | Field Border filter strips. |
| 3 Terracing | Contoured terraces on 3-8% slopes with sod outlets implemented on agricultural land. |
| 4 Field Diversions | Field diversion terraces at 40 m intervals on 3-8% slopes implemented on agricultural land. |
| 5 Agricultural Water Harvesting Ponds | Addition of ponds on farms for irrigation modelled as equivalent subbasin pond. |
| 6 Combined Application | Modifications for Scenarios 1, 2, 3, and 5 together. |

# Sasumua: Management scenario implications for policy and decision-making
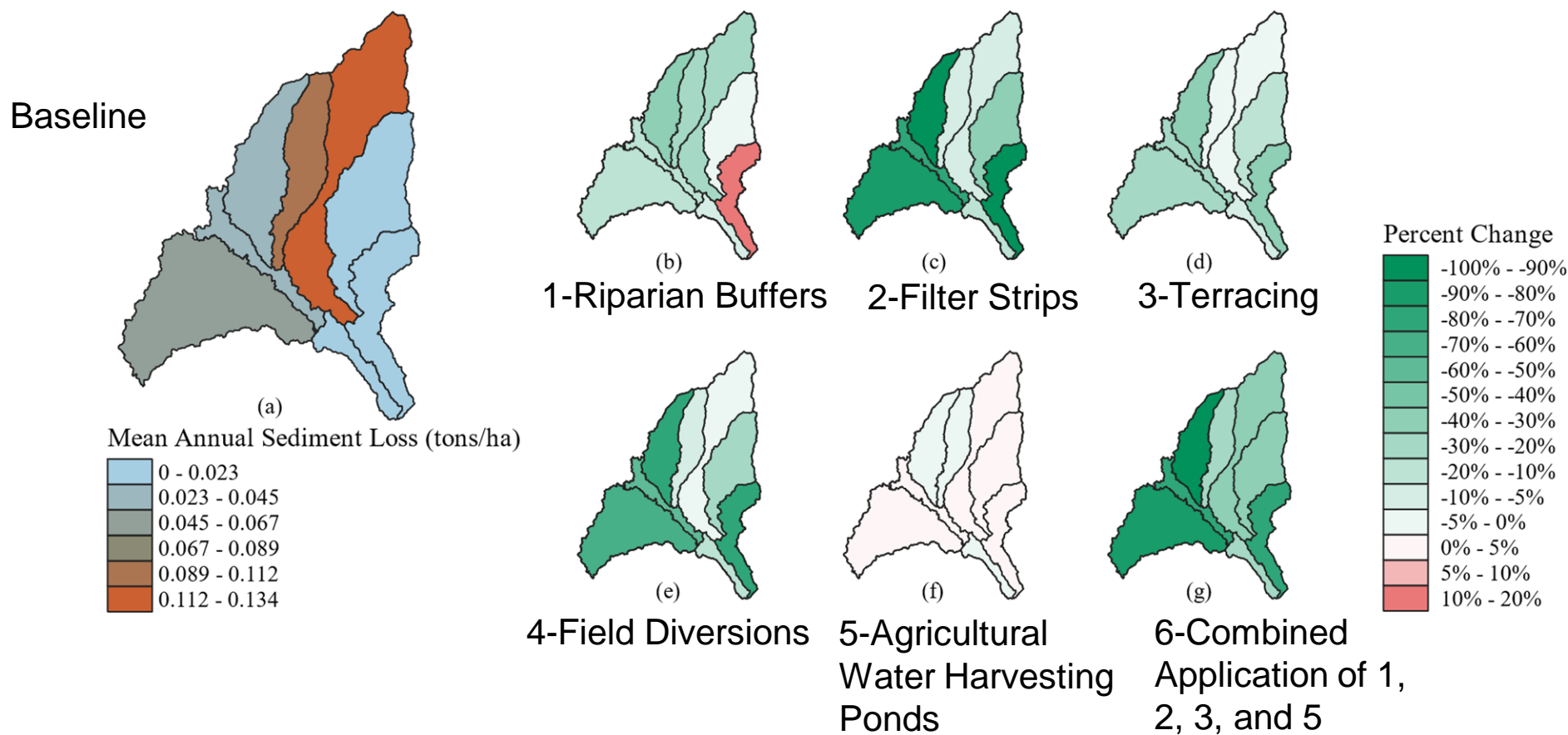


The combined management scenario 6 produced the most substantial results; scenario 2 was the most effective among single measures.
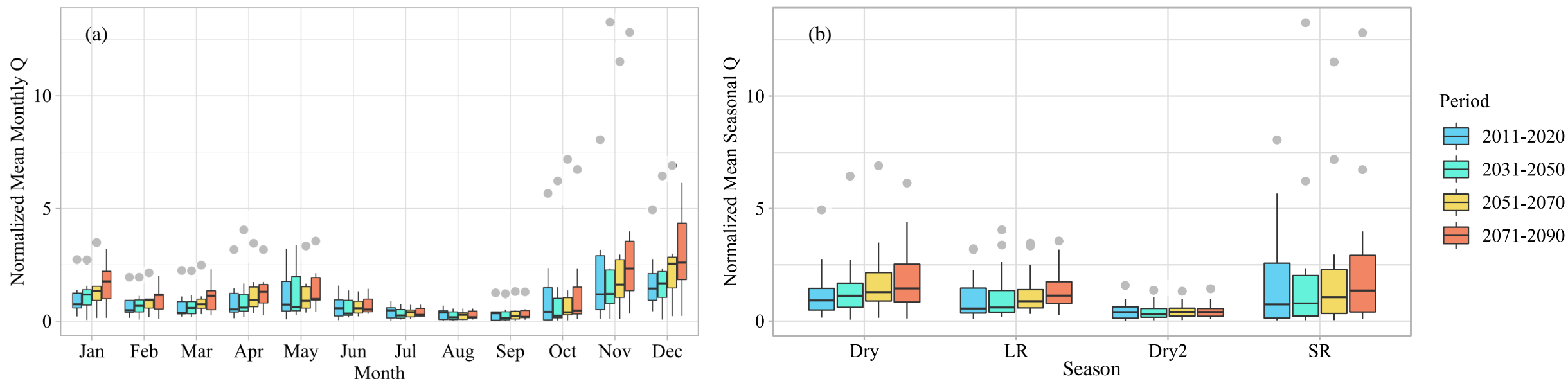
# Sasumua: Climate scenario implications for policy and decision-making
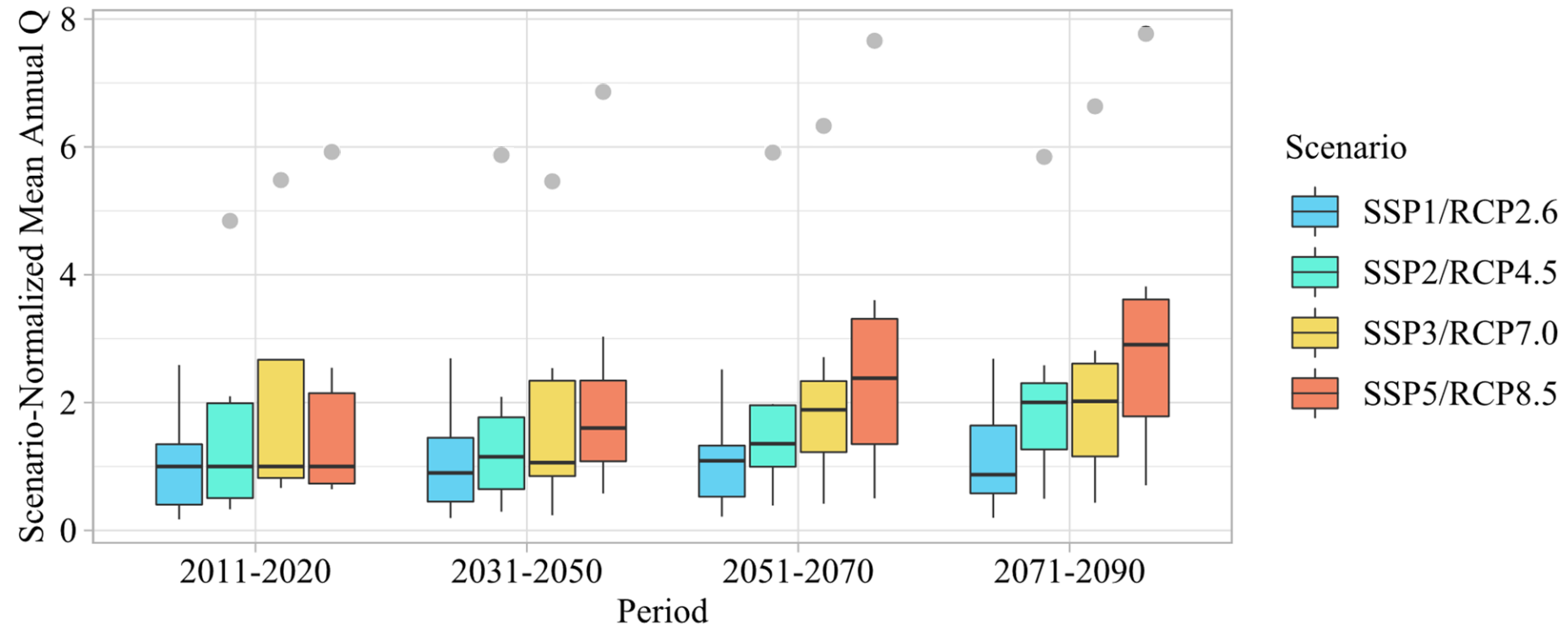
3 of 4 climate scenarios showed a flow increase of 2+ times the modern period.

# Sasumua: Climate scenario implications for policy and decision-making

- Monthly and Seasonal Flows for "Middle-of-the-Road" Scenario
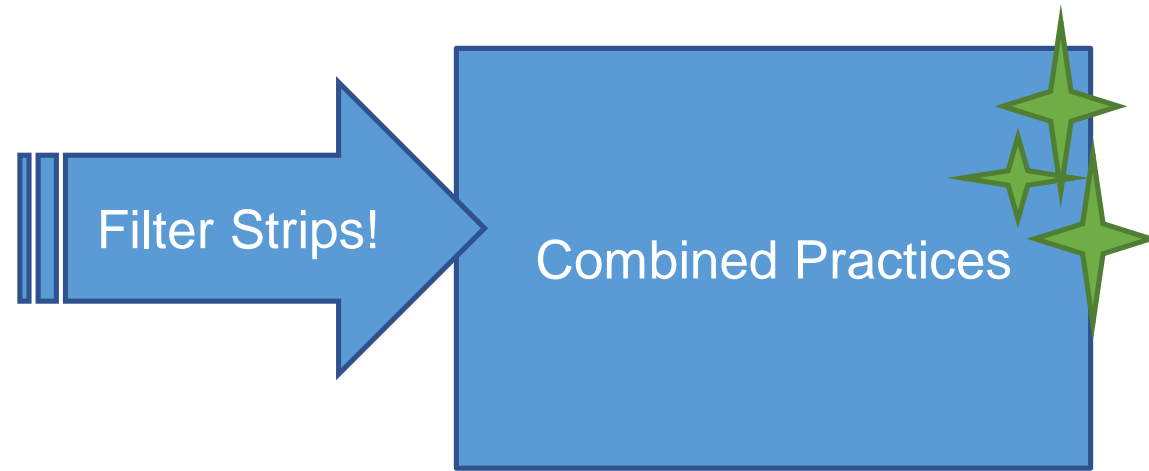


Flow increases for first dry and short rains season are projected (Nov/Dec/Jan) in response to more short rains precipitation.

# Sasumua: Findings

Filter Strips!

Combined Practices
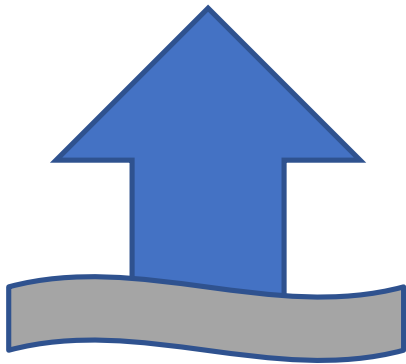
Flows for three of four future scenarios are in excess of double the 2011-2020 values.

The management practice scenario which was most successful at reducing basin losses was that which combined several practices together.

The single measure which resulted in the greatest positive impact when modelled was filter strips, suggesting the implementation of this practice at minimum.

Data policies must be updated to improve curation and access among relevant agencies to ensure that data is accessible for informing water resources management decisions.

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# Simiyu: Problem Statement

- Increased in Anthropogenic activities that have resulted in extensive Land Use changes

- The Simiyu river is reported to yield high amount of sediments, nitrogen and phosphorus draining into the Lake Victoria (Machiwa, 2003; Mwanuzi, 2006 Kimwaga et al., 2011)

- High rainfall fluctuations between seasons and from one year to the other, affecting the communities around the wetlands whose socio-economic activities are heavily dependent on the rainfall resulting in a reduction of agricultural and livestock production.

- Insufficient Data on the impacts of land uses and climate on the catchment hydrology

- Poor understanding of the Impacts of land uses and Climate changes of the catchment hydrology

# Simiyu: Study Objectives

- The Specific Goals:
    1. Analysis of the climate data from 1980 to 2019  and to the projected scenario 2030 - 2060 to identify periods of heavy rainfall, extended dry periods and trends in climate data
    2. Quantifying the Land Use Changes and Climate Changes in the Simiyu Catchment from 1970 to 2019
    3. Hydrological Modelling Using SWAT model to assess the Impacts of Land Use and Land Cover Changes on water budget components and sediments of the Simiyu Catchment
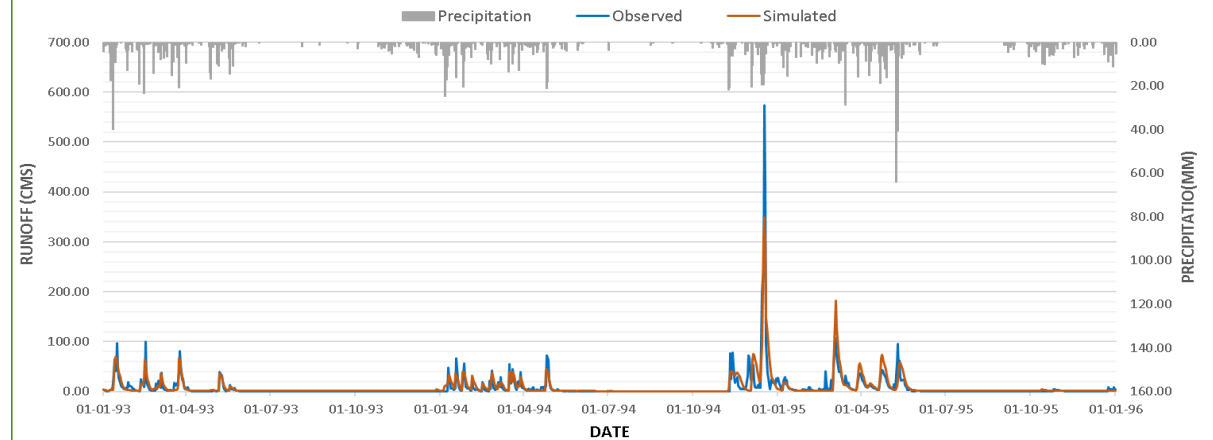
# Simiyu: Validation of model outputs

CALIBRATION PERIOD 1978 - 1992
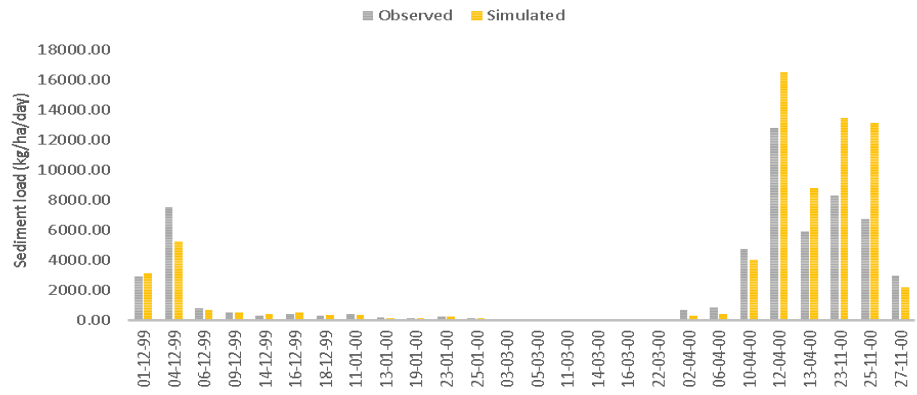
VALIDATION PERIOD 1993 - 1996
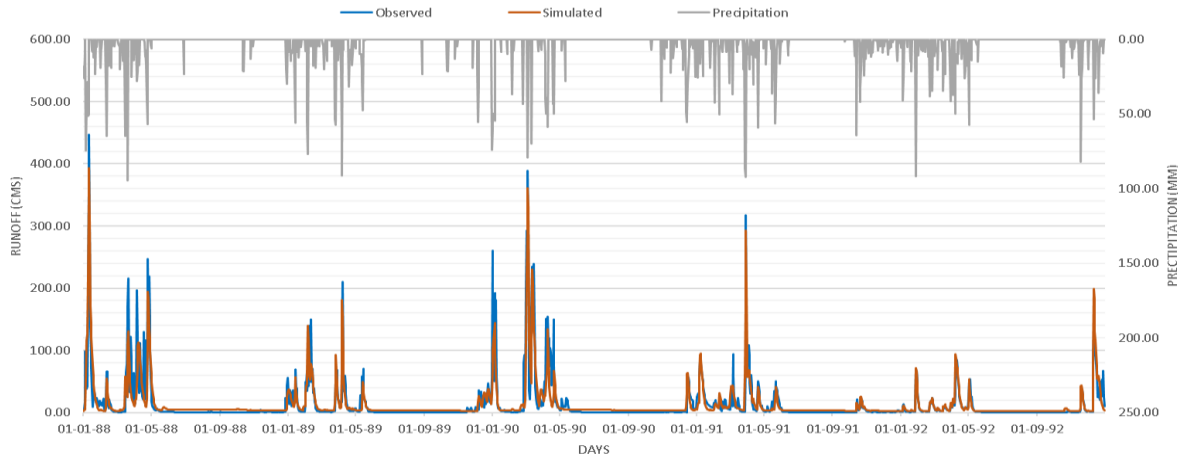


Slide Summary: 5% and 13% overall error for flow during calibration and validation periods. 22.1% overall error for sediments and nutrients

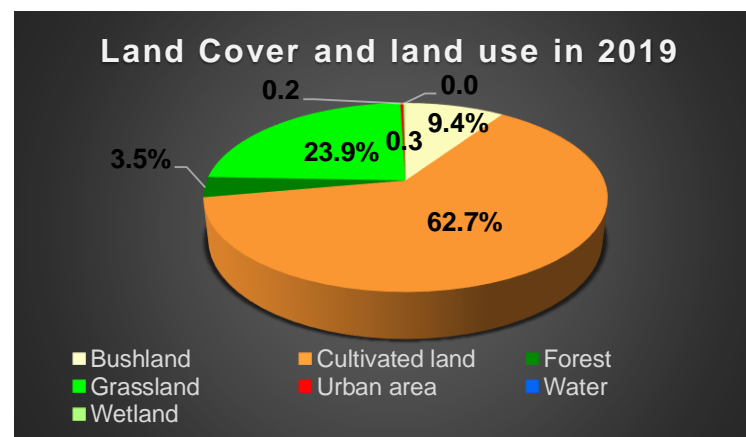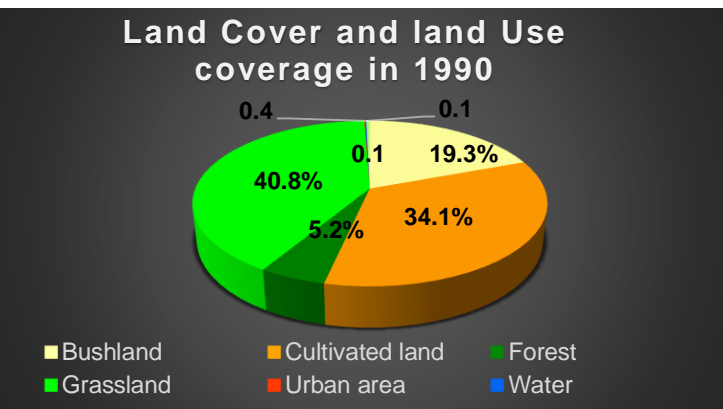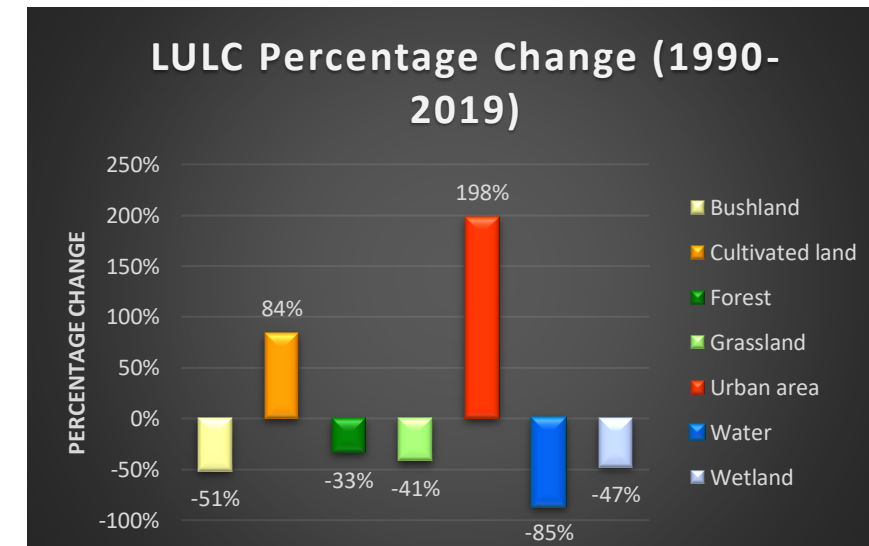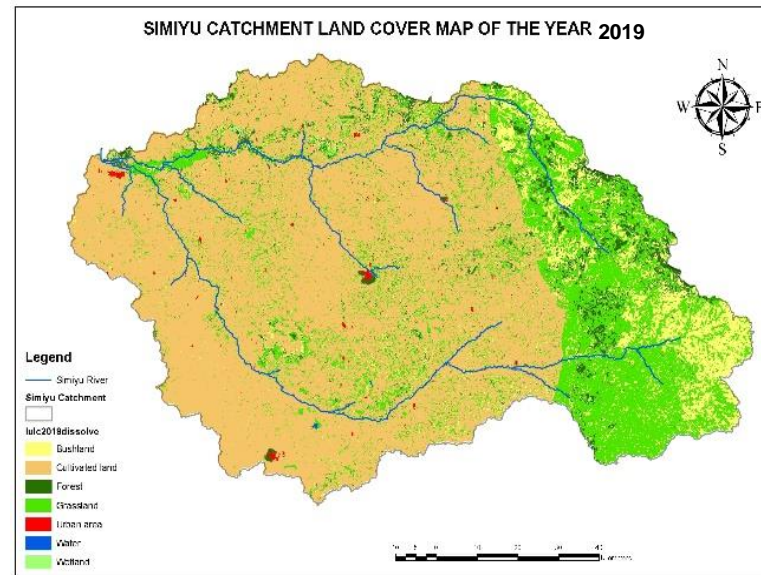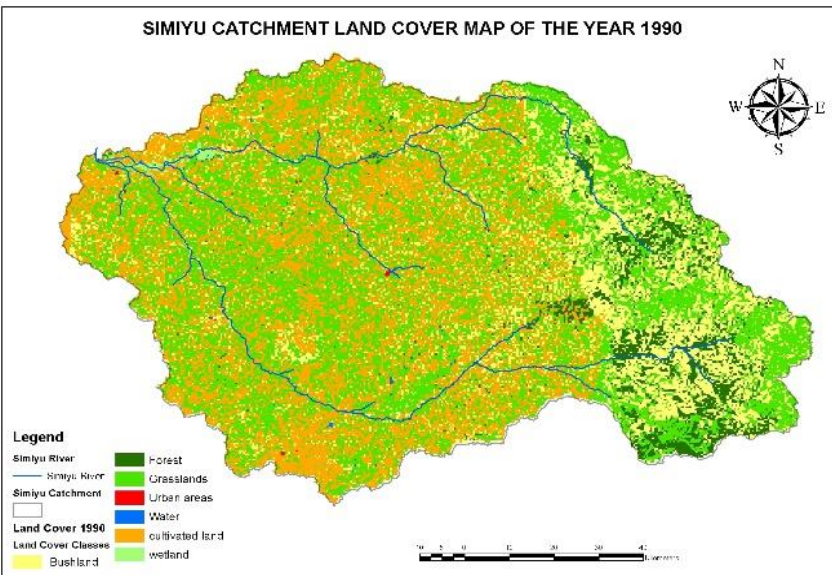# Simiyu: Scenario Descriptions

- Impacts of Land Use changes on the Catchment Water Balance



- Impacts of Climate Changes on the catchments Water Balance



Slide Summary: improper expansion of cultivated land in areas around Simiyu catchment. Recent studies have projected occurrence of flooding incidents in the catchment

# Simiyu Scenario Descriptions: Land Use Changes



SIMIYU CATCHMENT LAND COVER MAP OF THE YEAR 1990



SIMIYU CATCHMENT LAND COVER MAP OF THE YEAR 2019



LULC Percentage Change (1990-2019)



Land Cover and land Use coverage in 1990



Land Cover and land use in 2019

Slide Summary: Urban areas are increasing rapidly followed by the increase cultivated land in Simiyu catchment

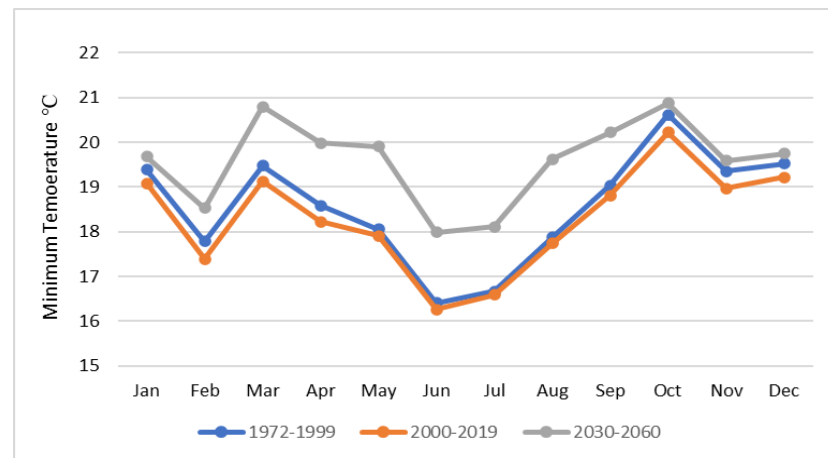# Simiyu Scenario Descriptions: Precipitation Changes
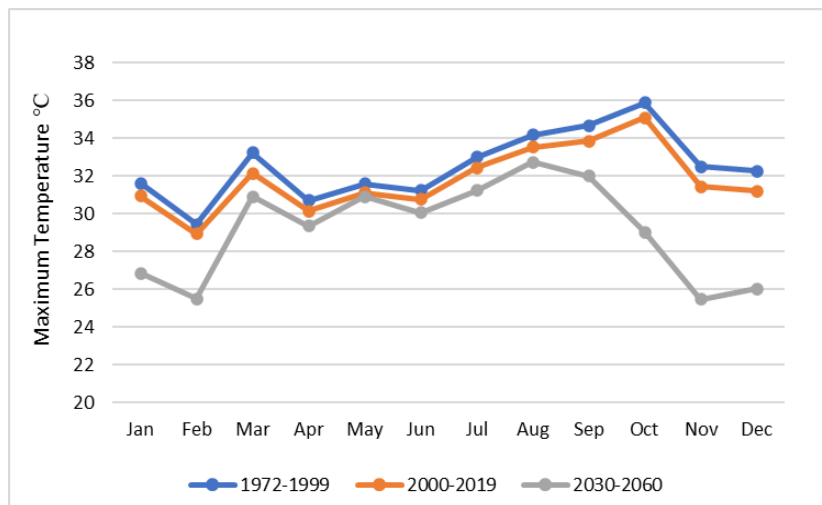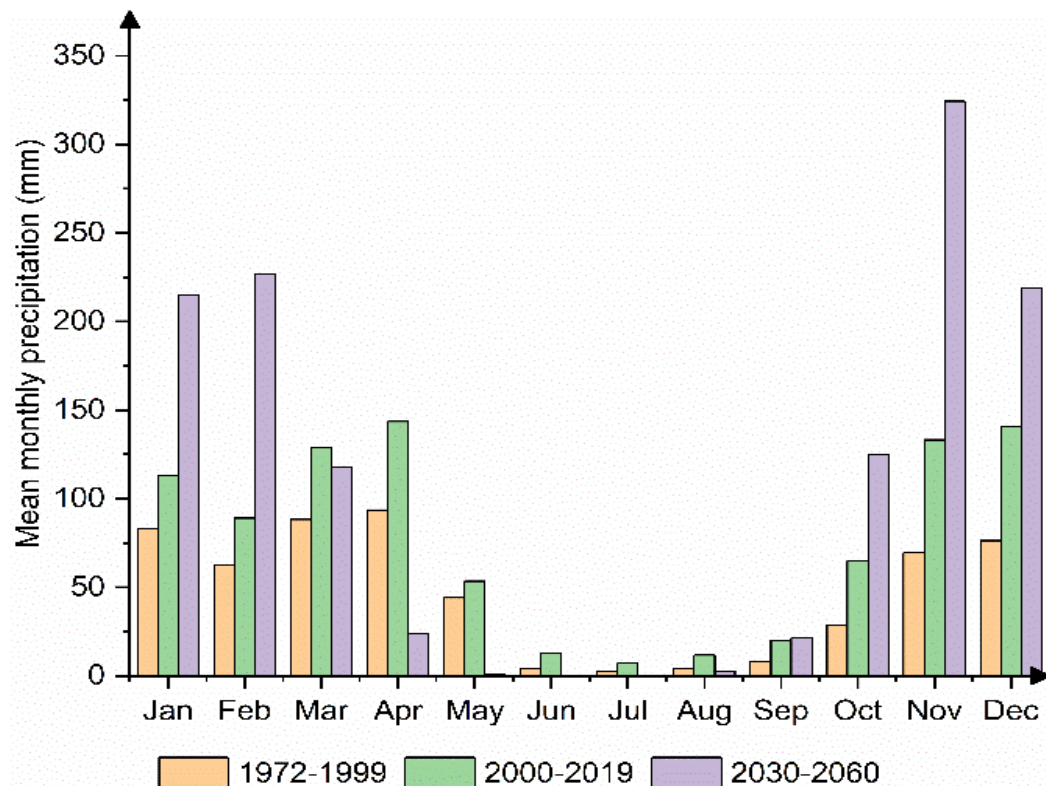


- Historical Dataset
- RCP 6.0

Slide Summary: precipitation in the current period increased by 62% as compared to the historical baseline period. In the future period, precipitation show an increasing trend of more than 100%.  Temperature is increasing with non-significant trend

# Simiyu: Model outputs of scenarios and implications

| Scenario Description | |
|---|---|
| Scenario 1 | Average annual change in water balance parameters with the change in climate from 1972/1988 - 2000/2019 |
| Scenario 3 | Projected average annual change in water balance parameter with the changing in climate condition from 1972/1988-2030-2060 |
| Scenario 2 | Average annual change in water balance parameters with the change in Land cover and land use in Simiyu watershed from 1990 to 2019 |



Impacts of Land Use Changes
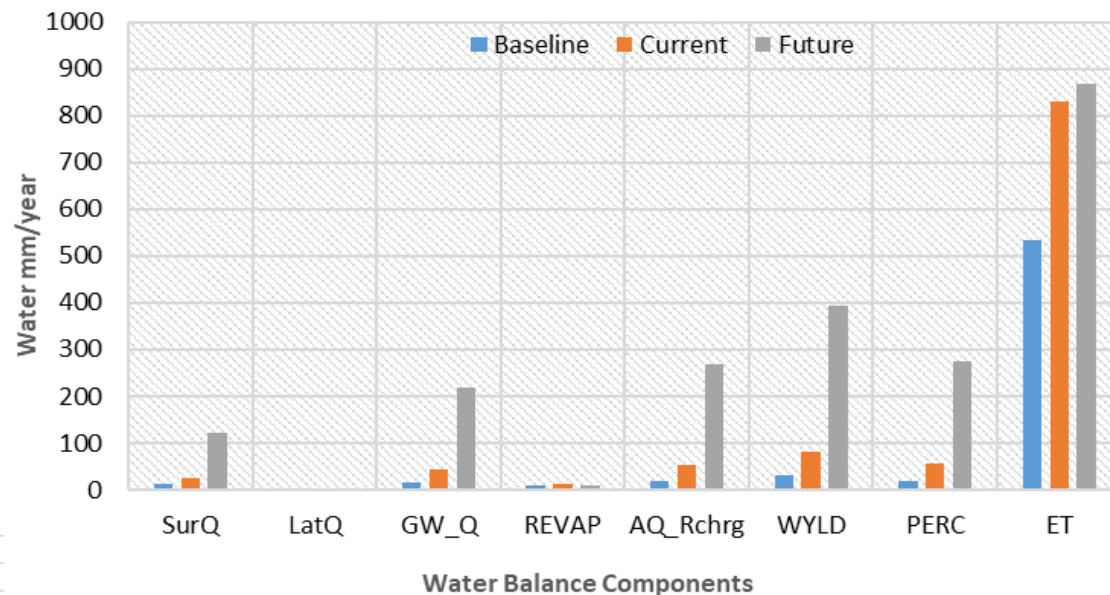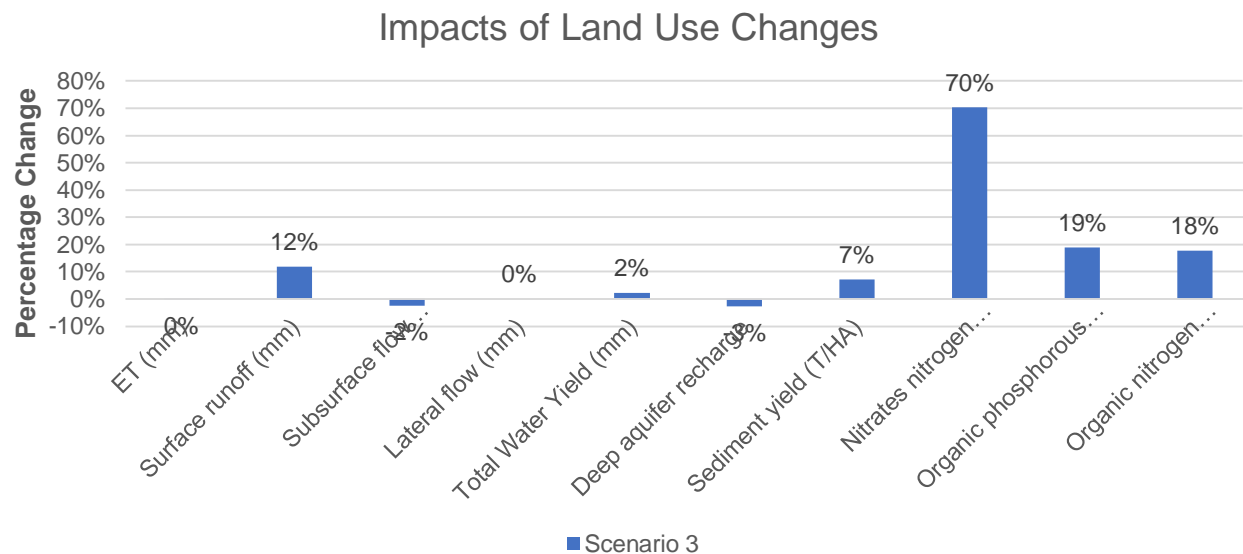


Slide Summary: Overland flow are increasing rapidly in all the climate scenarios averagely above 12 % Sediments is increasing by more tha 7% in land use change scenario

# Findings

- Projected climate show increase in surface run-off and the total Water yield in the catchment show possibility of flooding in the basin

- Rapid increase in Nutrient in the basin which indicates the increase of human and pollution activities in the catchment threating the integrity of the water quality

# Murchison Bay: Problem Statement

- The Murchison bay catchment has undergone several Human induced natural resources degradation and unregulated land use land cover changes (LULCC) over the last decade (Anaba et al, 2017).

- The current and future impacts of such changes on water quality and quantities are poorly understood and have not been predicted.

- Hence a study of the impacts of LULCC on catchment hydrology for better water resource management in the catchment.

# Murchison Bay: Study Objectives

**Overall Objective:** To assess the effects of Land use Land cover change on water quantity and quality in the Murchison Bay catchment of Uganda.

**Specific Objectives**
1. To assess the spatial and temporal nature of Land use Land cover changes in the Murchison Bay catchment in Uganda,

2. To calibrate and validate a SWAT model for the simulation of discharge and sediment yield for the Murchison Bay catchment,

3. To predict the future impacts of Land use land cover changes on water quantity and quality in the catchment.

# Murchison Bay: Calibration &Validation of model outputs
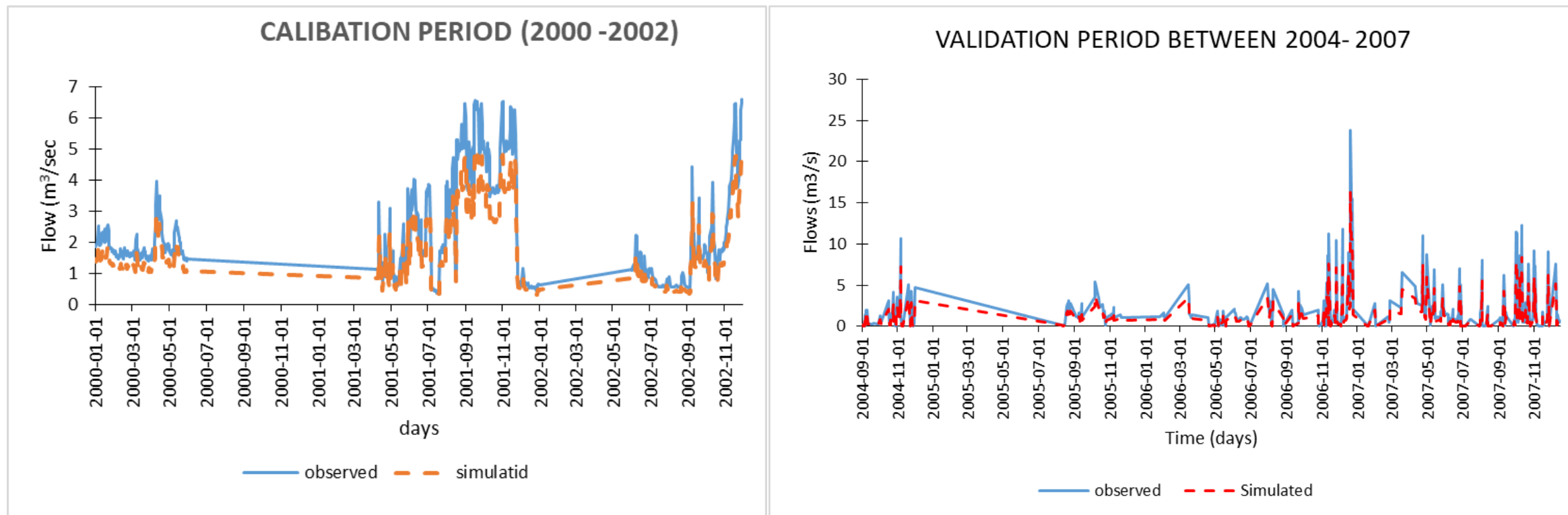


Slide Summary: Model over estimated flow during calibration but predicted perfectly during validation

# Murchison Bay validation out puts

Model Prediction Performance was considered satisfactory

| Stage Model | Evaluated statistics | | | |
|---|---|---|---|---|
| **Performance indices** | R2 | NSE | RSR | PBIAS |
| **Calibration (2000-2002)** | 0.74 | 0.72 | 0.43 | -0.05 |
| **Validation (2004-2007)** | 0.68 | 0.75 | 0.55 | 2.35 |

# Murchison Bay: Validation of model outputs

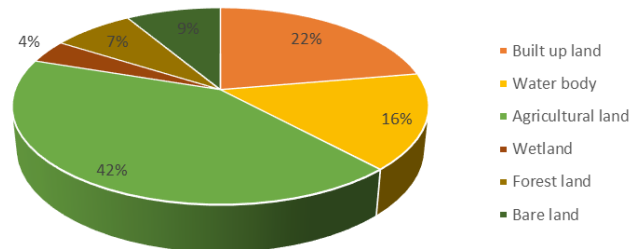| Stage | ET (%) | Surface Runoff(%) | Sediment (ton/ha) |
|---|---|---|---|
| Target | 80 | 30 | < 7 |
| Calibration | 45 | 18 | 0.17 |
| Validation | 38 | 24 | 0.23 |

Slide Summary: the flow was overestimated during calibration

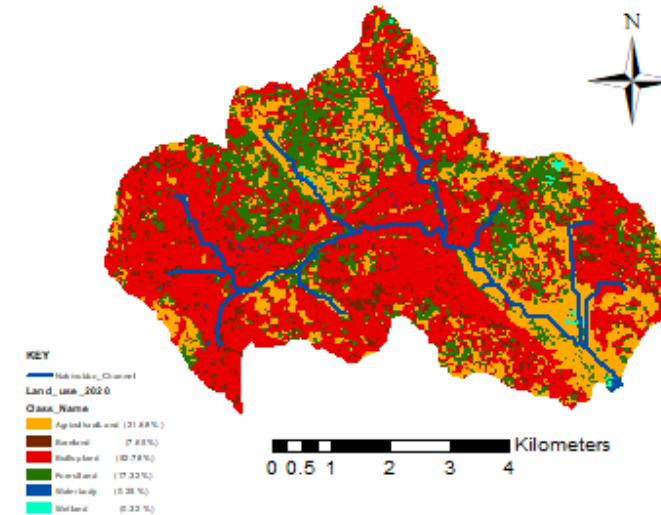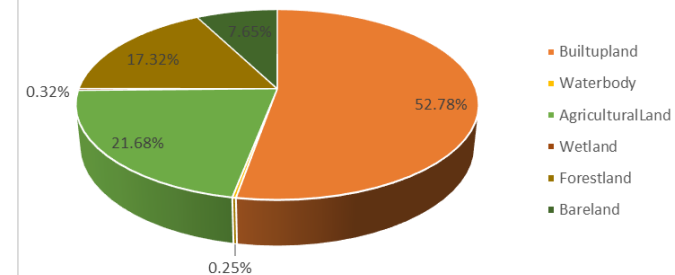## Murchison Bay: Scenario Descriptions Land use change between 2005 to 2020
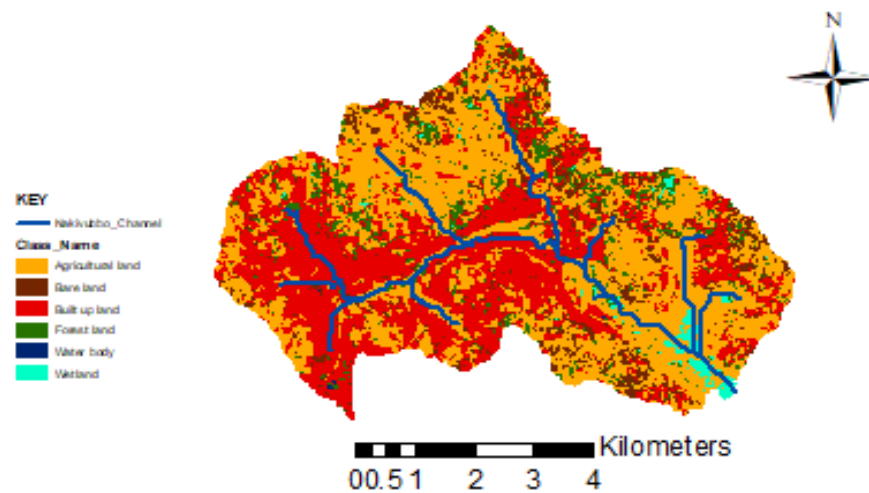
# Murchison Bay: Model outputs of scenarios and implications for policy and decision-making

| Component | Budget | Watershed | | |
|---|---|---|---|---|
| | | Scenario1 (mm) Baseline (2000) | Scenario 2 (mm) Predicted output 2030 | Scenario 3 Predicted output 2040 |
| Water quantity | ET (mm) | 581 | 588 | 589 |
| | Surface runoff (mm) | 269 | 298 | 310 |
| | Subsurface flow (baseflow) (mm) | 725 | 716 | 706 |
| | Soil moisture (mm) | 20 | 19 | 19 |
| | Stream flow(mm) | 993 | 1015 | 1015 |
| | Discharge (mm/day) | 736 | 1024 | 1023 |
| | Deep aquifer recharge | 38 | 37 | 36 |
| Water quality | Soil erosion | | | |
| | Sediment yield(T/ha) | 13 | 12 | 12 |
| | Total nitrogen (Kg/ha) | 150 | 164 | 171 |
| | Nitrates nitrogen (leaching) (Kg/ha) | 69 | 62 | 62 |
| | Total phosphorus(Kg/ha) | 26 | 29 | 31 |
| | Total soluble phosphorus(Kg/ha) | 0 | 0 | 0 |
| | Organic phosphorous(Kg/ha) | 2 | 2 | 1 |
| | Organic nitrogen(Kg/ha) | 16 | 12 | 11 |

Slide Summary: SWAT Outputs Between the year 2000 to 2020, 2030, 2040

# Murchison Bay: Scenario Descriptions, Best management Practices(BMPs)

| Management scenario | Response |
| --- | --- |
| 1. Vegetation Filter strips(VFS) | Both Back Yard and compound strips instead of paved surfaces, but also garden borders |
| 2. Grassed waterways | These were applied at the mean width (GWATW) 1 m, 2 m, 5 m at shorter length ranging between 0.5 km to 1 km, since Murchison bay is in the city |
| 3. Surface runoff detention Ponds | At the backyard of every infrastructure and along highways (1 m width, 2 m , 5 m and 10 m ) |

# Murchison Bay: Model outputs of scenarios and implications for policy and decision-making
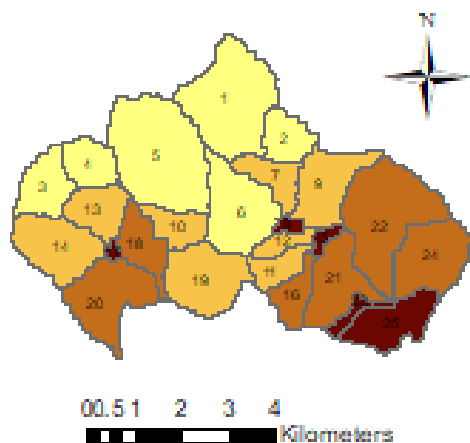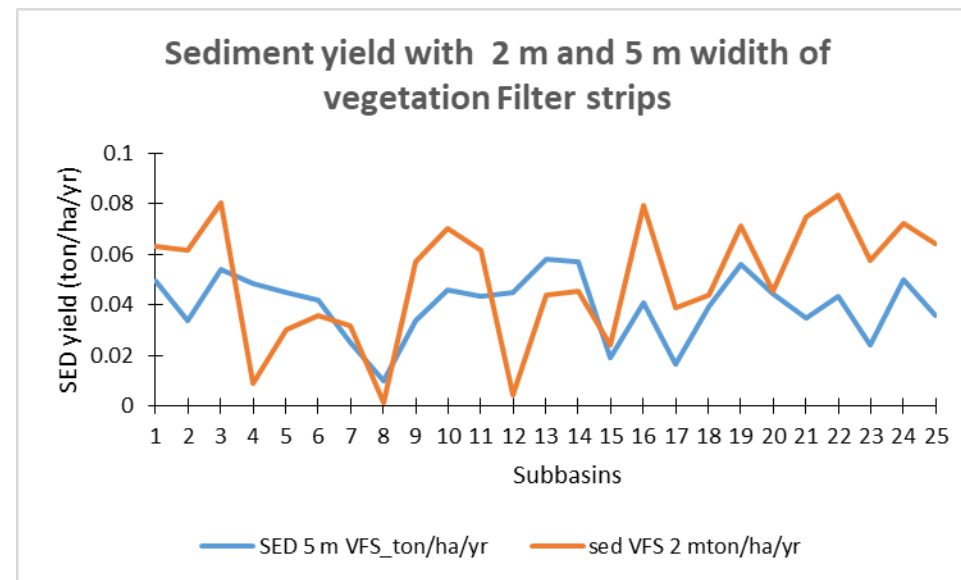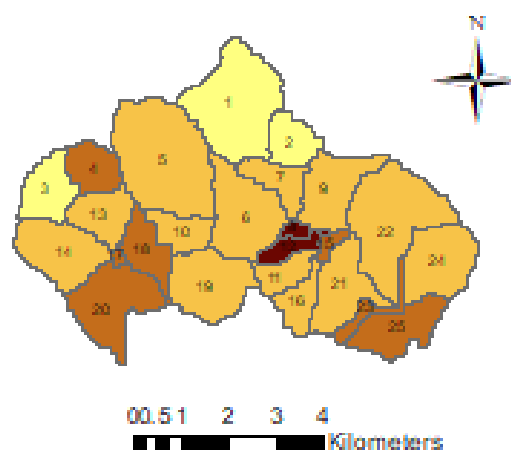


Slide Summary: the Vegetation filter strip at 2 m reduces sediment yield by 21 %

# Tying things together

- Over the last 20 year the Murchison Bay has undergone several land use land cover changes with built up land increasing at faster rate of 0.7%.

- This explains why the Stream flow is increasing and floods as indicated by scenario results.

- The increasing population in the catchment is the leading driver of wetland loss and increased sediment yield over the years and the deteriorating water quality in the catchment.

# Best Management practices recommended

1. Planting of vegetation filter strips at filter width of 2 m reduced sediment yield by 42% and 5 m by 70% in all subbasins.

2. The retention ponds of 20 m$^3$ reduced surface run of by 60% in the catchment. However, the grassed waterways presented minimal impact.

3. The interventions are leading to increased groundwater recharge, hence people in low areas will have to be resettled.

# **Tying Things together**

Therefore, sustainable environmental management measures are suggested:

i.    Sensitizing the masses on proper waste management,

ii.   Improved drainage structures with grass strips,

iii.  Demarcation of buffer zones and enforcement against encroachment at least 30 m from the riverbanks and 300 m form the lake,

iv.   Rainwater harvesting promotional campaigns to control excess roof and ground surface runoff water.

# Discussion Questions

1. What can be done to ensure data are available in ample quantities for use with modeling applications?

2. How many of are familiar with use of model for work like this one? What specific topics would you be interested more about with respect to modeling?

3. What management practices are you familiar with?
   - Specifically – how is the riparian buffer defined for policy and decision-making in each country?