Presentation given the TransLinks workshop:

Modeling and Managing Watersheds

September 13-16, 2011

Kigali, Rwanda
Umubano Hotel, Boulevard de l'umuganda

This workshop was hosted by the Wildlife Conservation Society, the United States Forest Service (USFS) and the United States Agency for International Development (USAID)

This workshop was generously supported by the American people through the United States Department of Agriculture (USDA) Forest Service and the United States Agency for International Development (USAID), under the terms of the TransLinks Cooperative Agreement No.EPP-A-00-06-00014-00 to the Wildlife Conservation Society (WCS). TransLinks is a partnership of WCS, The Earth Institute, Enterprise Works/VITA, Forest Trends and the Land Tenure Center. The contents are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States government.

Modeling and Managing Watersheds Workshop:

Results and Recommendations for the Luangwa Valley, Zambia

Steve McNulty, Ge Sun, Erika Cohen and Matt Wingard

Eastern Forest Environmental Threat Assessment Center
Southern Research Station
USDA Forest Service, Raleigh NC

September 14, 2011; Kigali, Rwanda

Outline

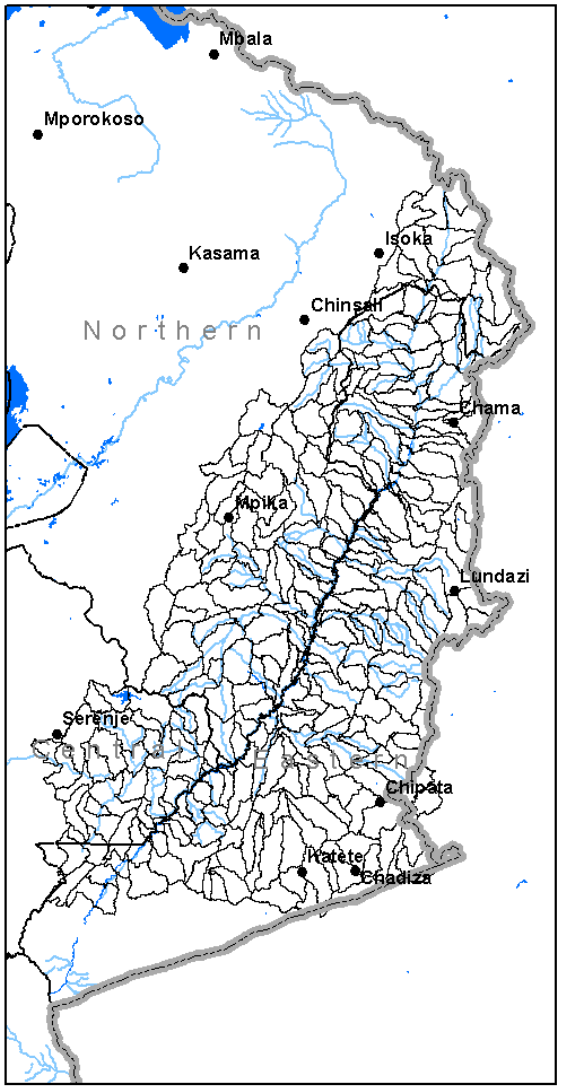
- Goals
- Study Location
- Physical Characteristics
- Environmental Issues
- Results
  - Outputs
  - Validation
- Summary and Recommendation

Goals

- Model water quantity and sedimentation within the Luangwa River Landscape with current landcover conditions

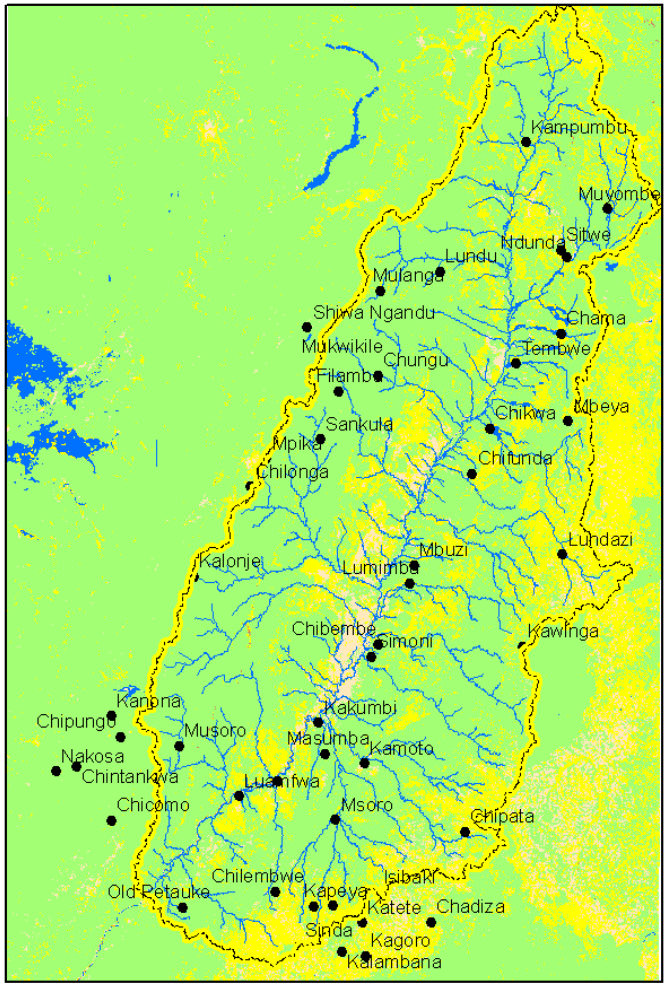
- To simulate landuse and/or climate change within the modeling framework and quantify its impact on water quantity and sedimentation

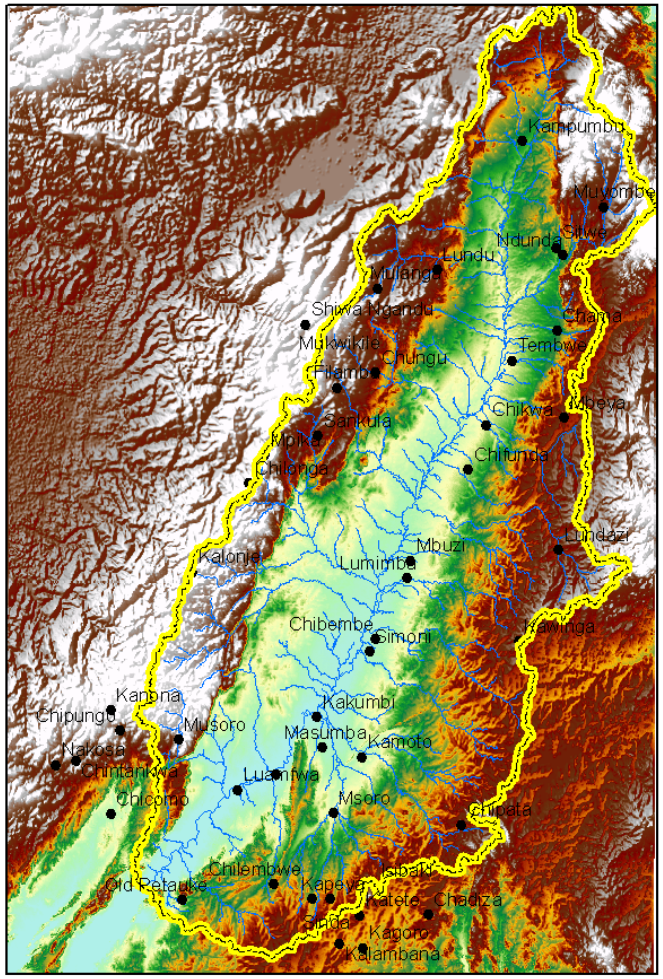

Luangwa Valley
Sumbu
Mbala
Mporokoso
Kawambwa
Luwingu
Kasama
Isoka
Northern
Chinsali
Mansa
Samfya
Chama
Mpika
Lundazi
Mwinilunga
Solwezi
Chingola
Nchanga
Kalulushi
Kitwe
Ndola
Luanshya
Serenje
Zambezi
North-Western
Mkushi
Chipata
Kapiri Mposhi
Eastern
Katete
Chadiza
Kabwe
Mumbwa
Mongu
Lusaka
Western
Mazabuka
Southern
Choma
Livingstone
Study Location


Mbala
Mporokoso
Kasama
Isoka
Northern
Chinsali
Chama
Mpika
Lundazi
Serenje
Eastern
Chipata
Katete
Chadiza

Input Databases

Data	Spatial Resolution	Temporal Resolution	Time Step	Source
Temperature and Precipitation	0.5° x 0.5°	1960-2009	Monthly	Climate Research Unit (CRU) Time-Series (TS) Dataset 3.1; The University of East Anglia
Leaf Area Index	1km x 1km	2000-2006	Monthly	Zhao et al.,2005; Numerical Terradynamic Simulation Group (NTSG) at the University of Montana Missoula MODIS Imagery, MOD15(FPAR/LAI),
Landcover	300m x 300m	2009	static	Globcover, European Space Agency (ESA), MERIS instrument
DEM	30m x 30m		Static	ASTER





Landuse

- Cropland
- Grassland
- Forest
- Shrubland, Savanna
- Sparse Vegetation, Barren Land
- Wetland, Water

- Towns

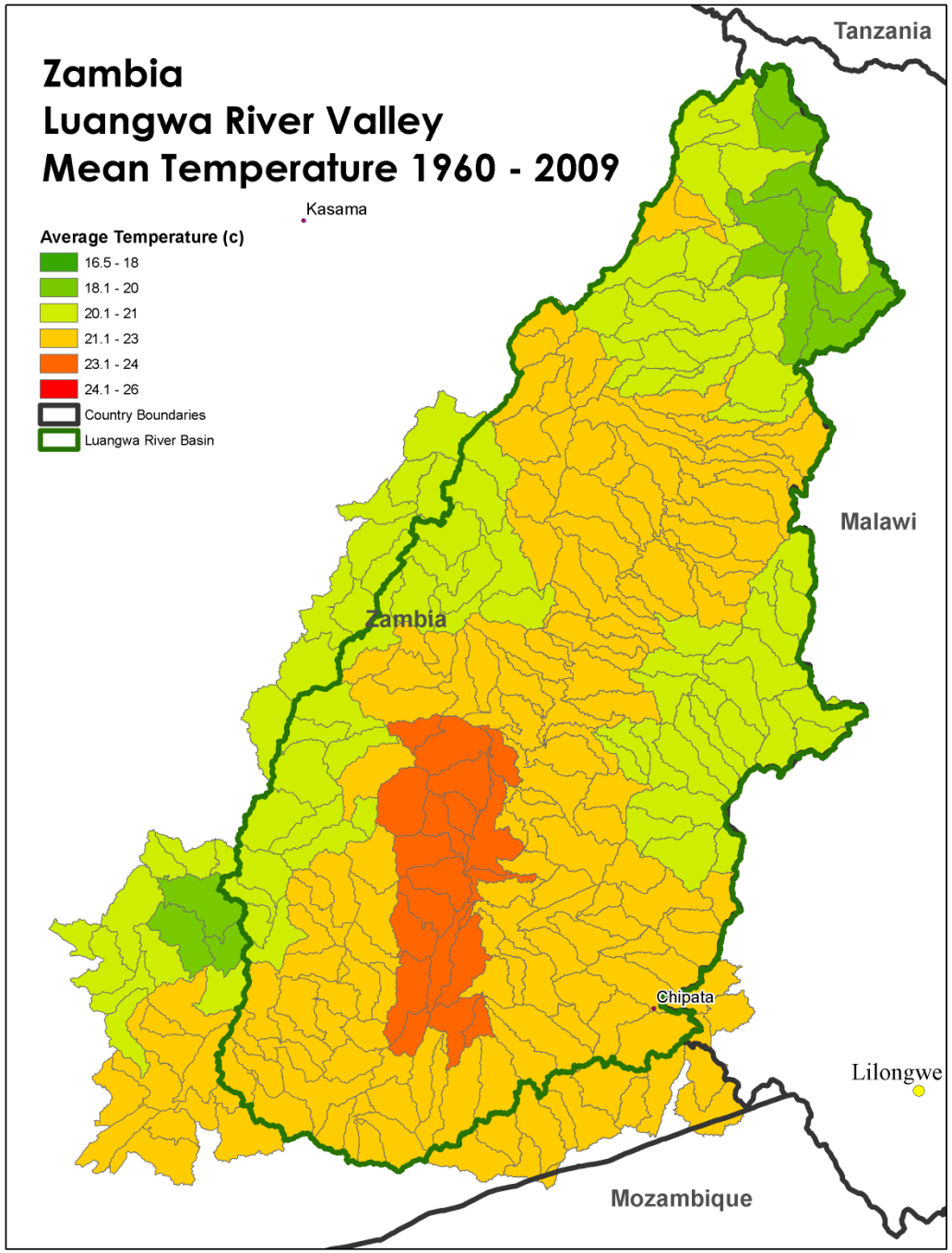
Luangwa River

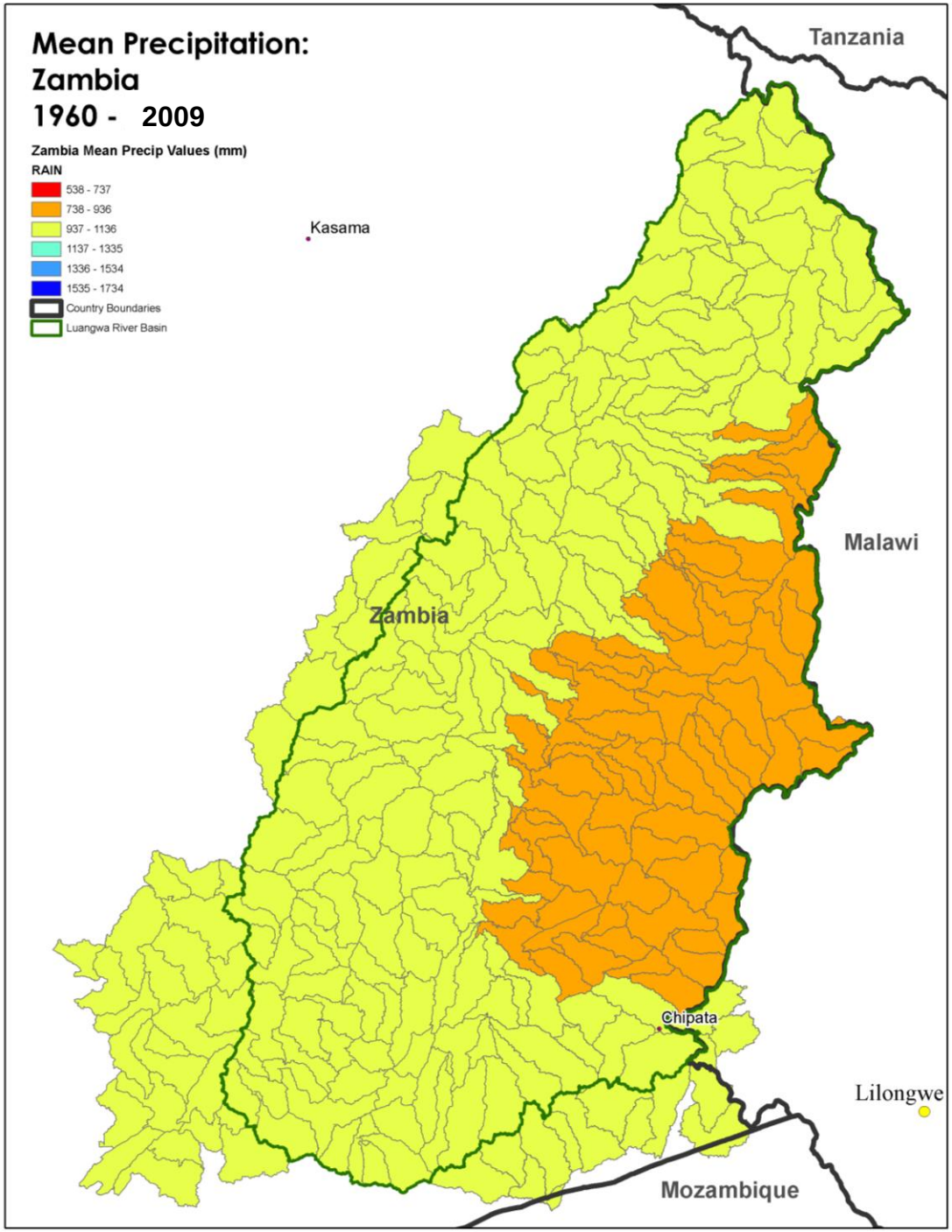
- Watershed Boundary

Elevation (m)

High : 2315

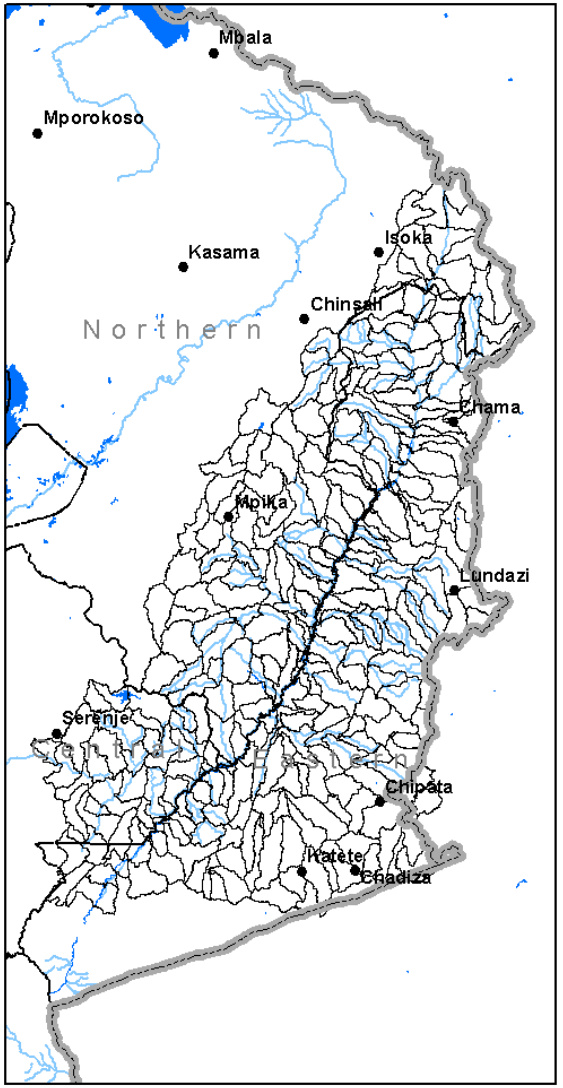
Low : 407


Zambia
Luangwa River Valley
Mean Temperature 1960 - 2009
Kasama
Average Temperature (c)
16.5 - 18
18.1 - 20
20.1 - 21
21.1 - 23
23.1 - 24
24.1 - 26
Country Boundaries
Luangwa River Basin
Tanzania
Malawi
Zambia
Chipata
Lilongwe
Mozambique


Mean Precipitation:
Zambia
1960 - 2009
Zambia Mean Precip Values (mm)
RAIN
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1734
Country Boundaries
Luangwa River Basin
Tanzania
Kasama
Malawi
Zambia
Chipata
Lilongwe
Mozambique

Environmental Issues

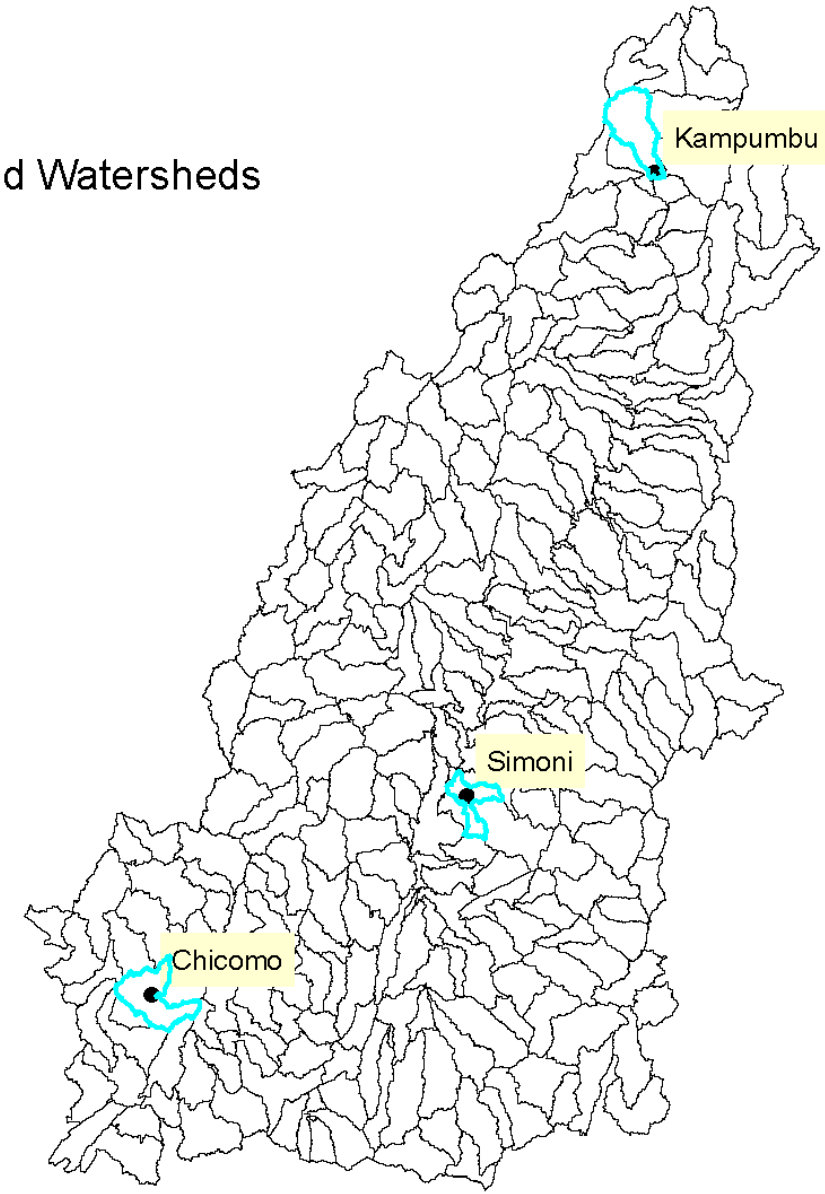
- Excessive clear cutting of forest
  - Make charcoal
  - Grow crops
- Over farming land
  - Stripping land of all nutrients
  - Erosion

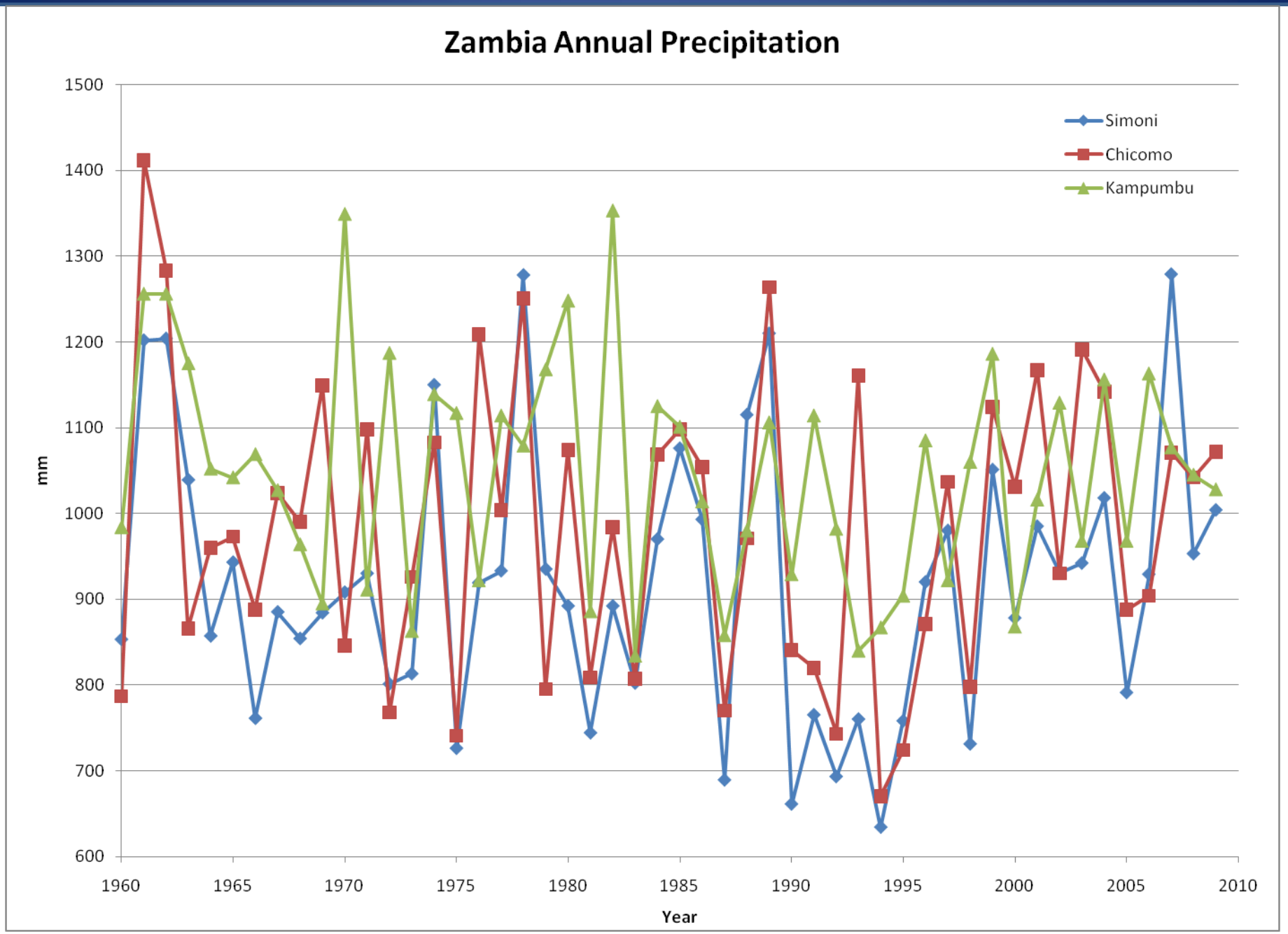


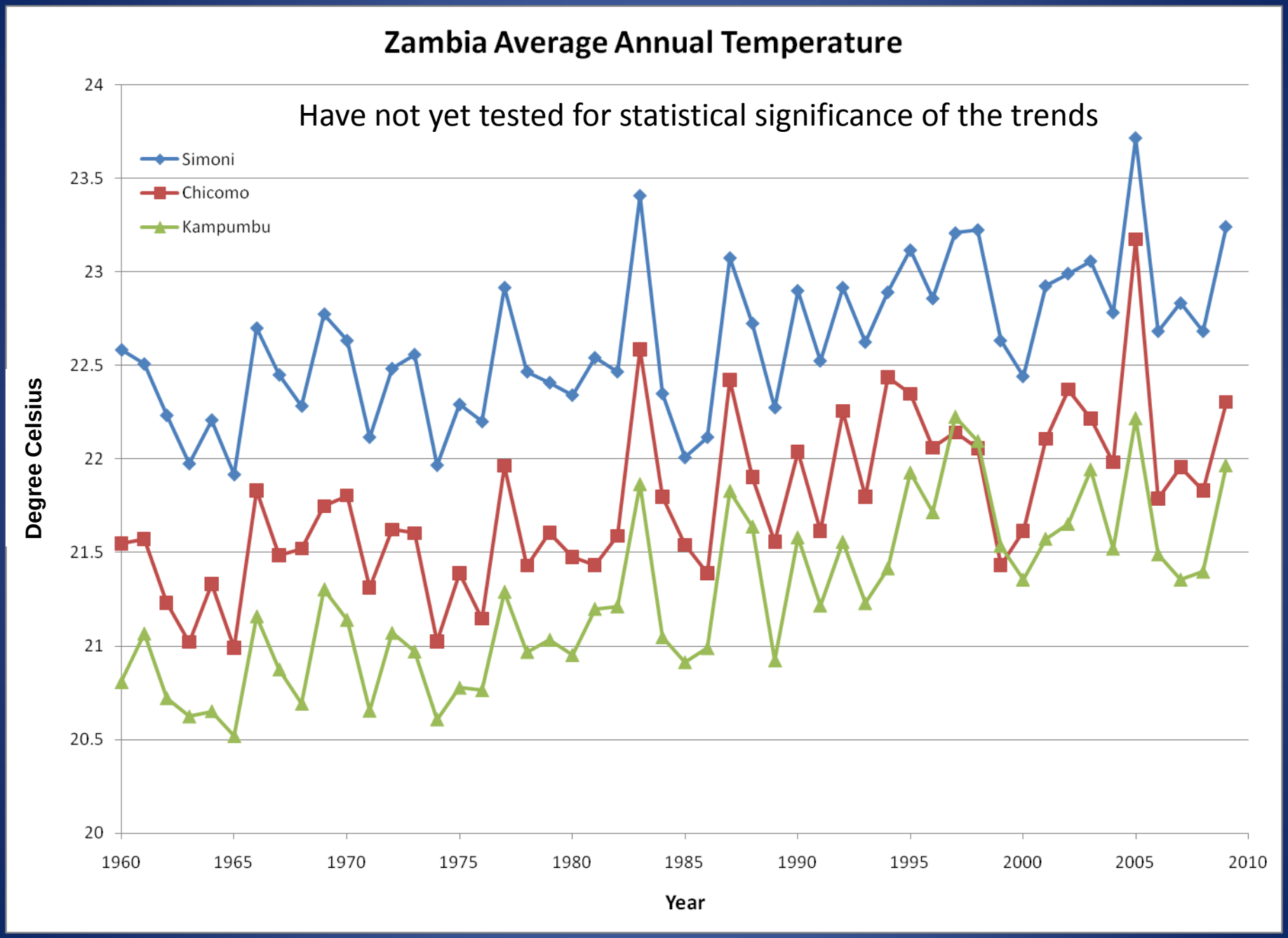
Result Scenario: Water Quantity

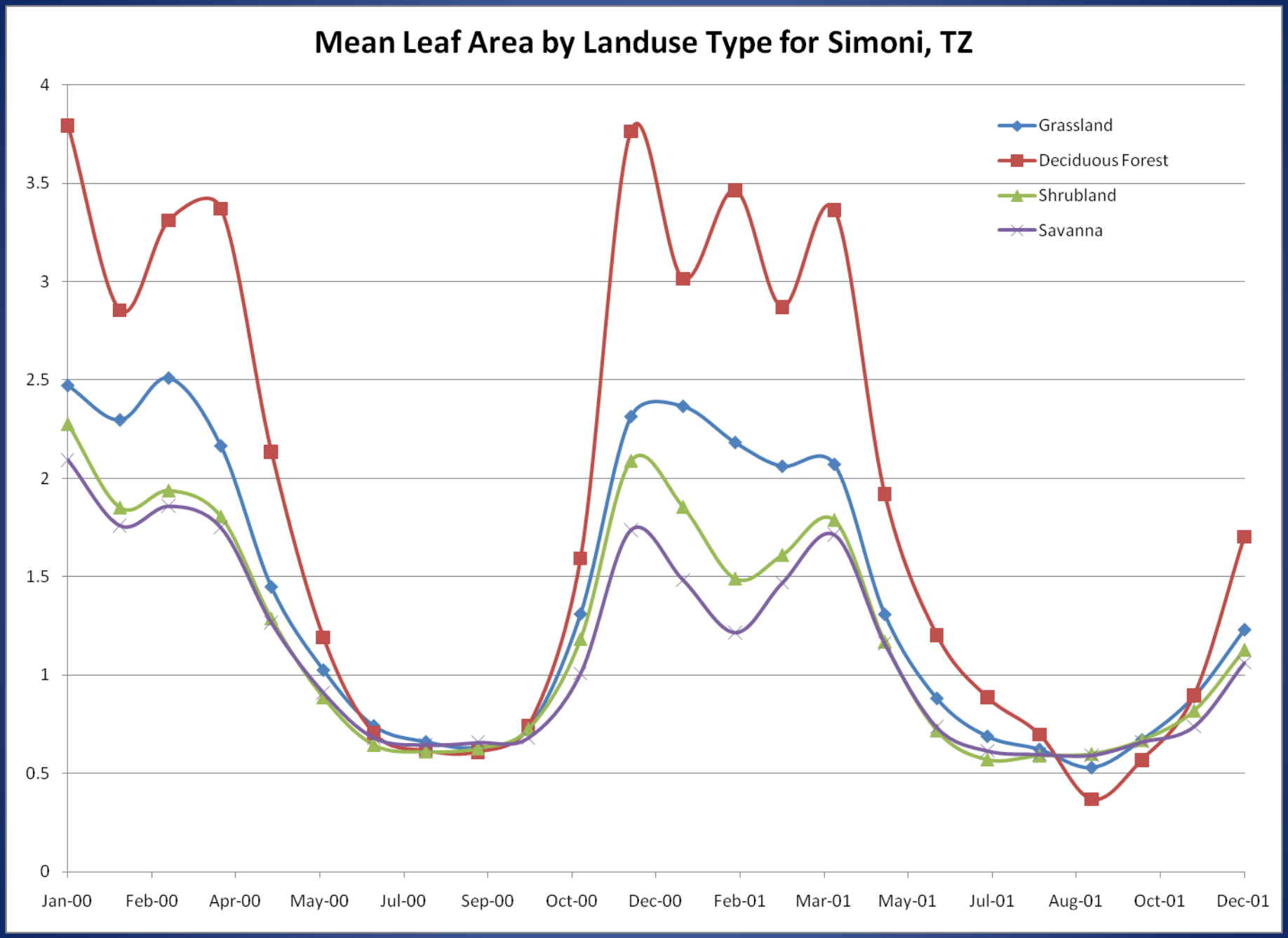
- Scenarios (4)
  - Baseline
    - 2009 landcover
    - Monthly precipitation and temperature from 1960-2009
  - Converting 20% of forest to cropland
  - 1^{o} C temperature increase
  - 1^{o} C temperature increase + 10% reduction in precipitation

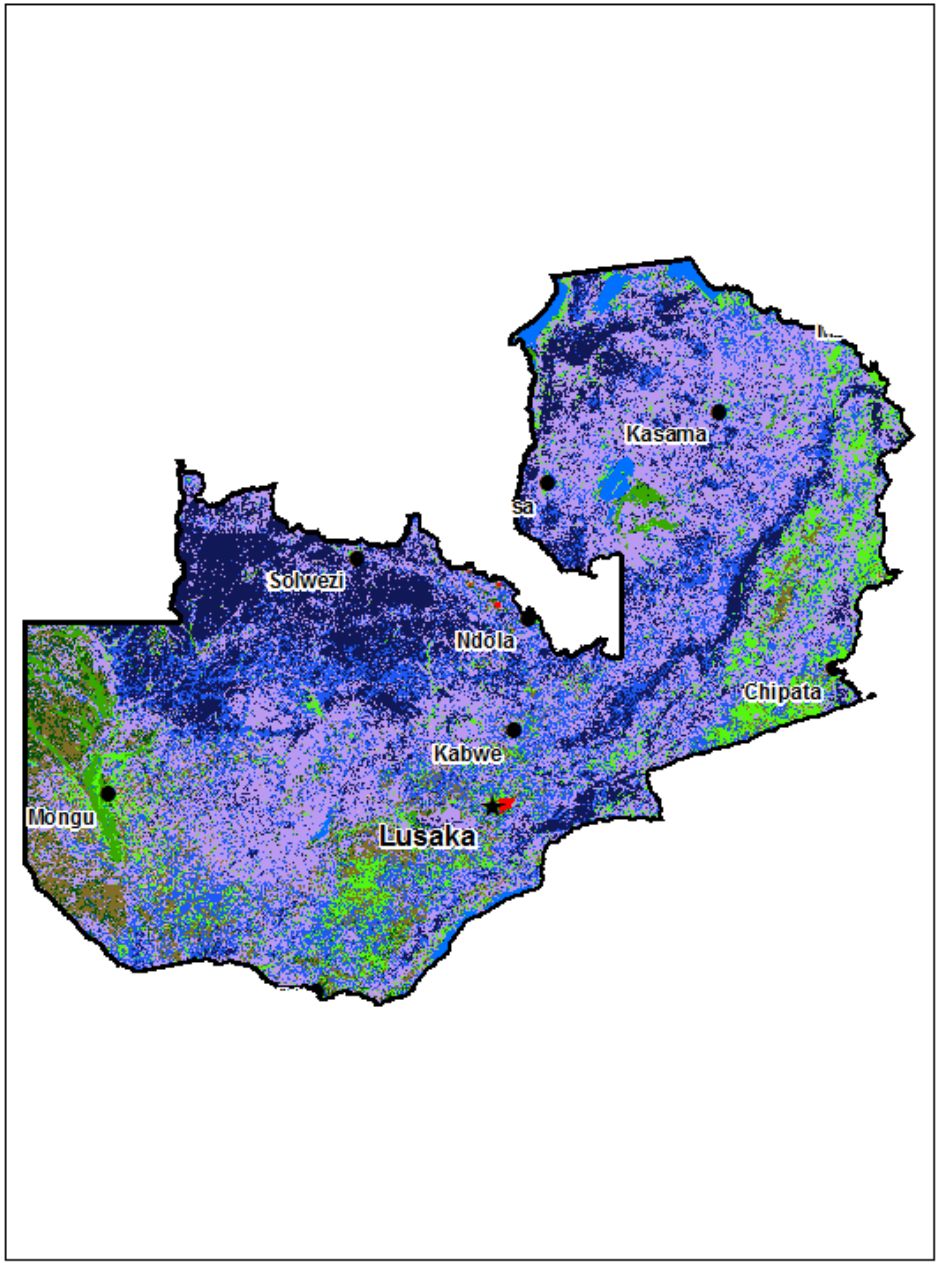
Zambia Selected Watersheds




Zambia Annual Precipitation
1500
1400
1300
1200
1100
1000
900
800
700
600
mm
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Simoni
Chicomo
Kampumbu


Zambia Average Annual Temperature
Have not yet tested for statistical significance of the trends
Simoni
Chicomo
Kampumbu
Degree Celsius
Year
24
23.5
23
22.5
22
21.5
21
20.5
20
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


Mean Leaf Area by Landuse Type for Simoni, TZ
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan-00
Feb-00
Apr-00
May-00
Jul-00
Sep-00
Oct-00
Dec-00
Feb-01
Mar-01
May-01
Jul-01
Aug-01
Oct-01
Dec-01
Grassland
Deciduous Forest
Shrubland
Savanna



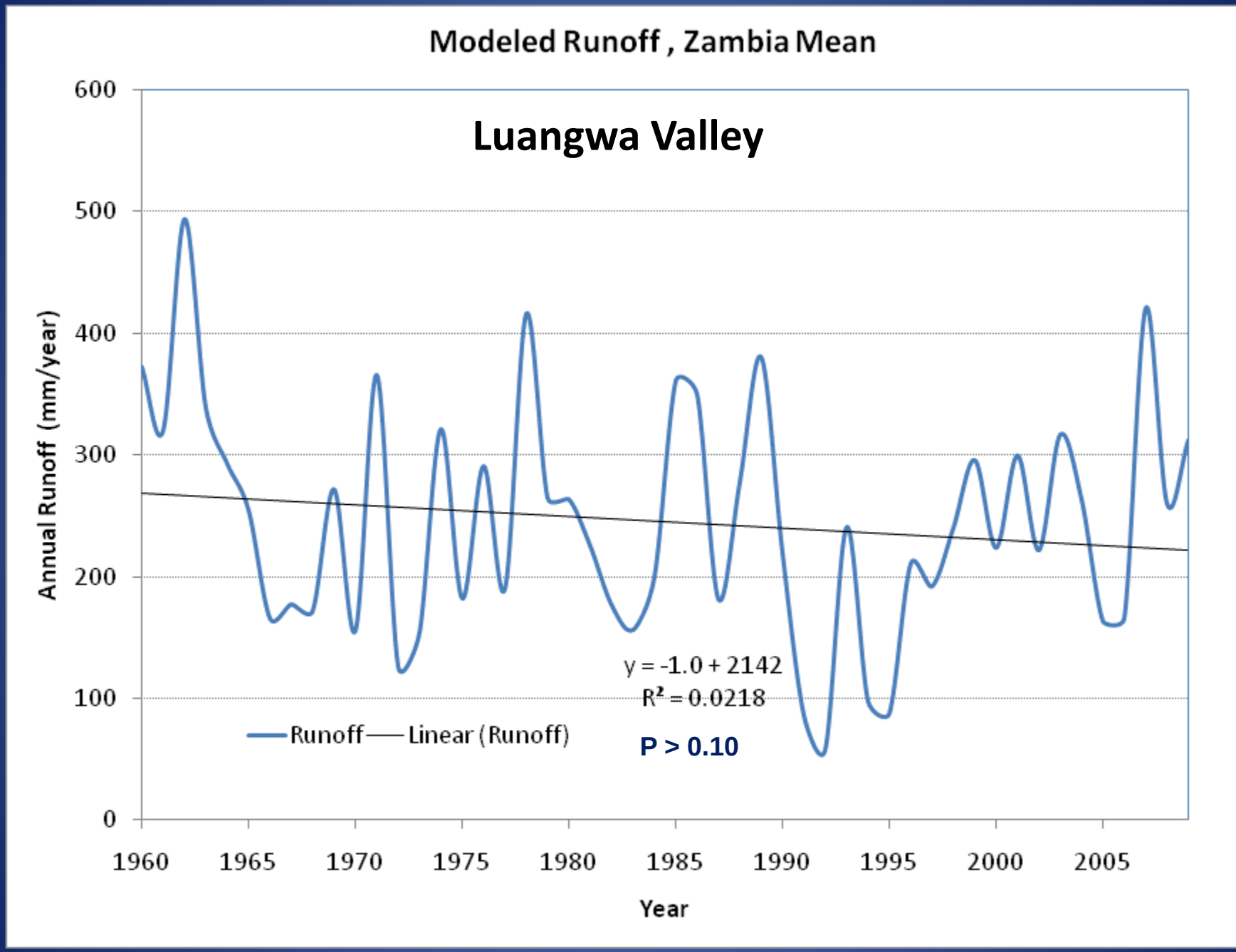
Zambia

300 meter resolution
Land Cover
Globcover Dataset 2009

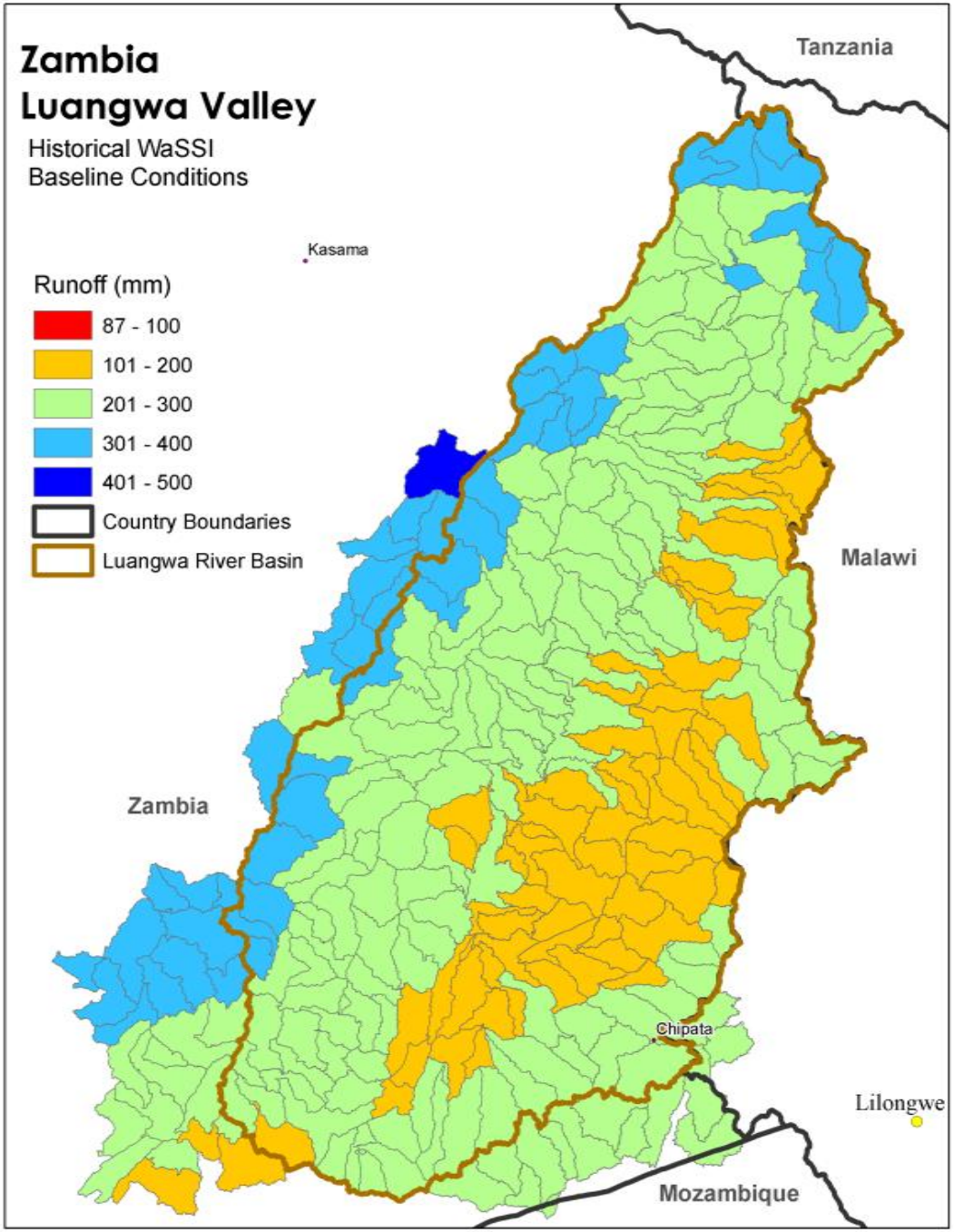
Land Cover Types

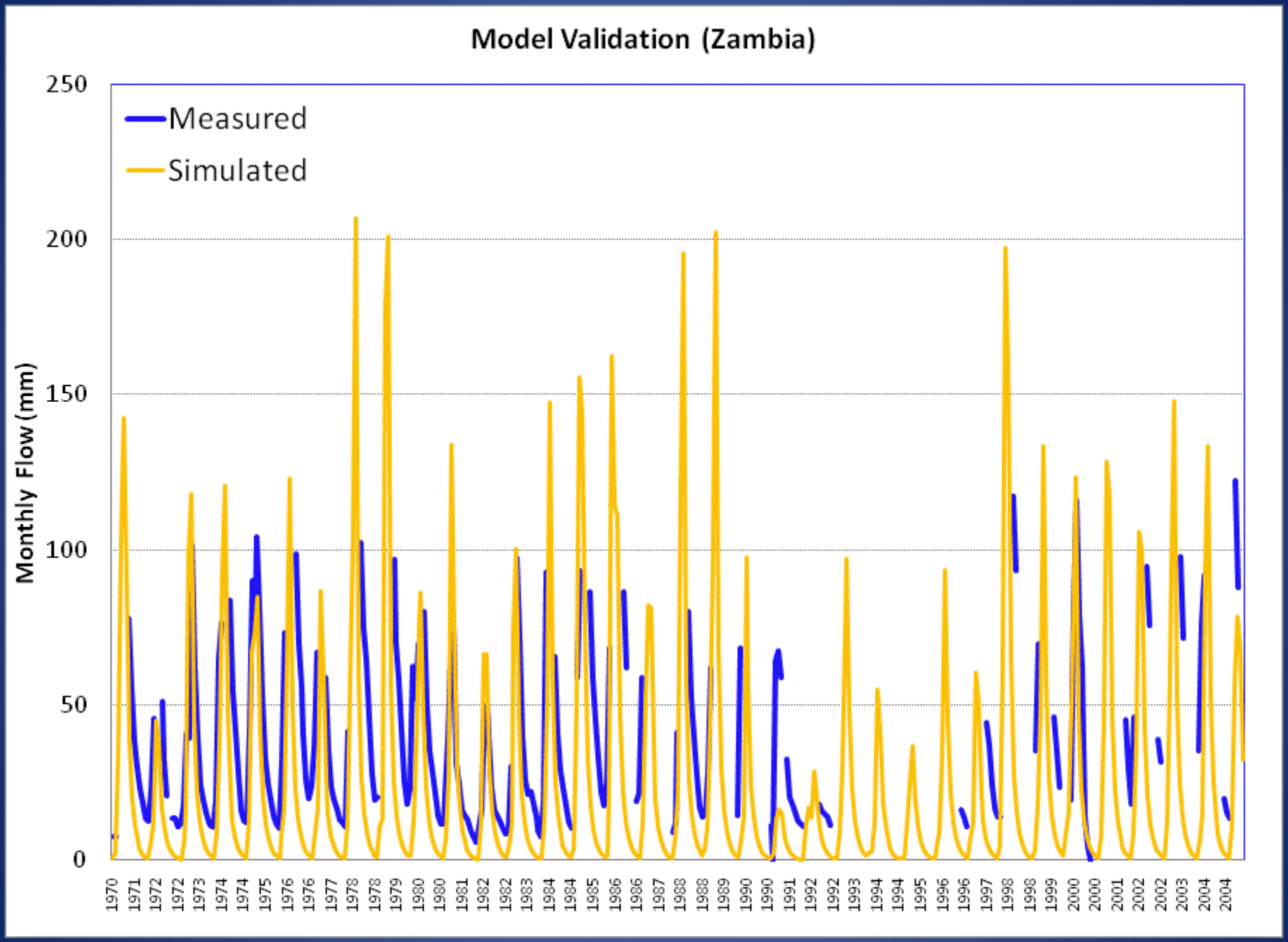
- Post-flooding or irrigated croplands
- Rainfed croplands
- Mosaic cropland (50-70%)
- Mosaic vegetation
- Closed to open (> 15%) broadleaved deciduous forest
- Closed (>40%) broadleaved deciduous forest
- Open (15 - 40 %) broadleaved deciduous forest
- Closed needleleaved evergreen forest
- Open needleleaved deciduous or evergreen forest
- Closed to open mixed broadleaved and needleleaved forest
- Mosaic forest or shrubland
- Mosaic grasland
- Closed to open shrubland
- Closed to open herbaceous vegetation
- Sparse Vegetation
- Closed to open flooded broadleaved forest
- Closed broadleaved forest permanently flooded
- Closed to open grassland or woody vegetation on waterlogged soil
- Artificial Surfaces and associated areas (Urban > 50%)
- Bare Areas
- Water bodies
- Permanent Snow

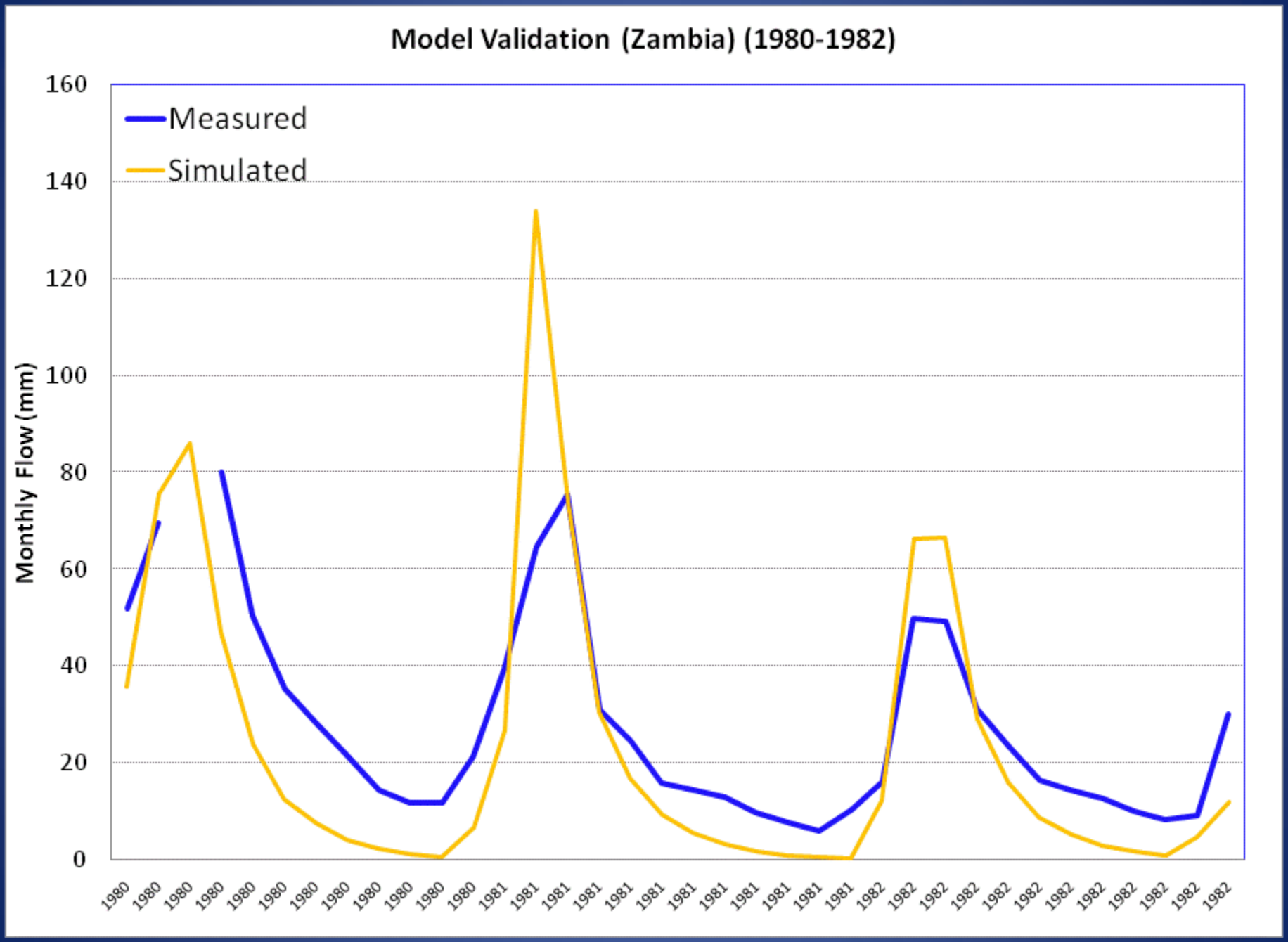
Model Output

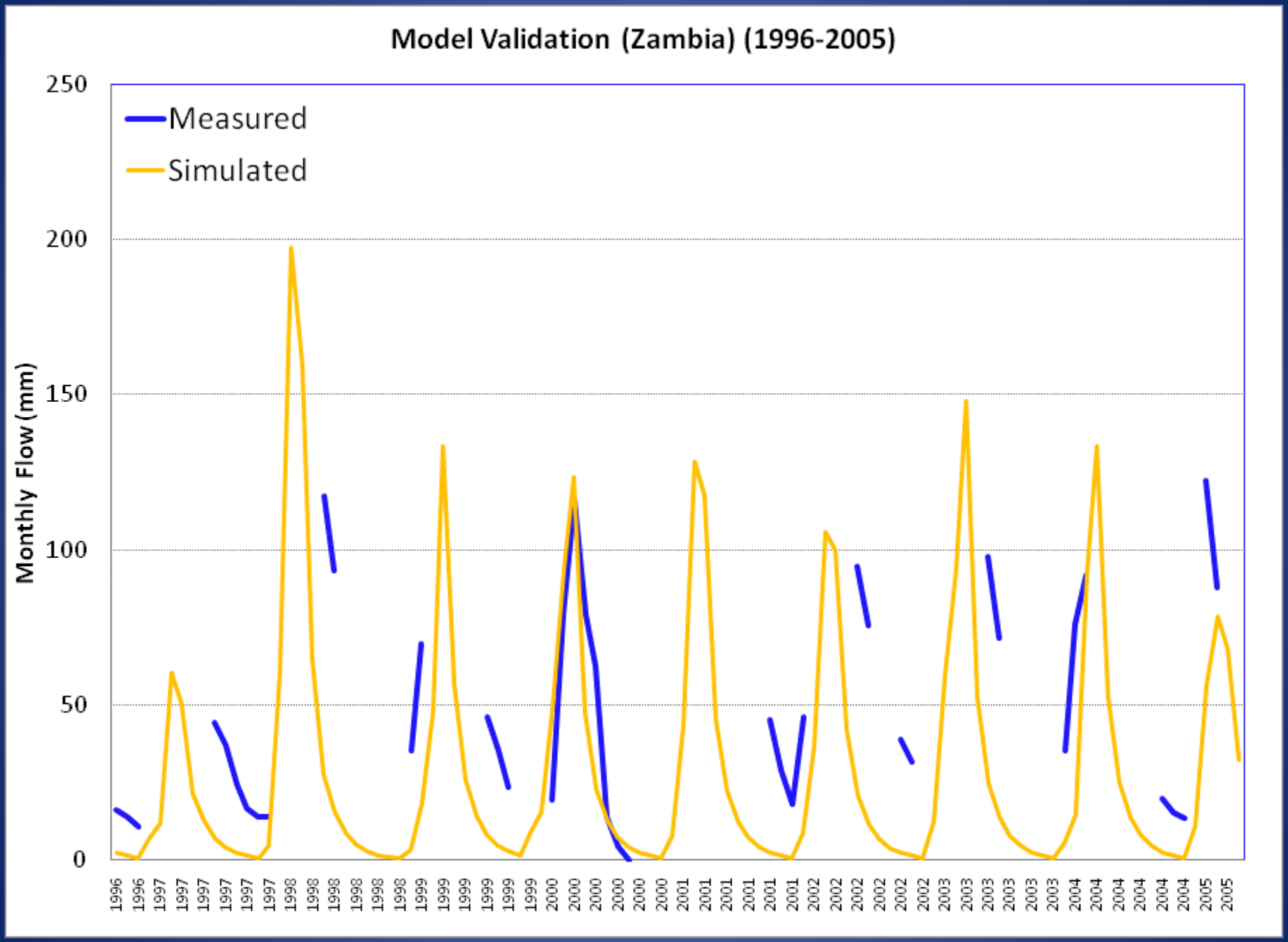

Modeled Runoff , Zambia Mean
Luangwa Valley
Annual Runoff (mm/year)
600
500
400
300
200
100
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
y = -1.0 + 2142
R² = 0.0218
Runoff
Linear (Runoff)
P > 0.10

Validation

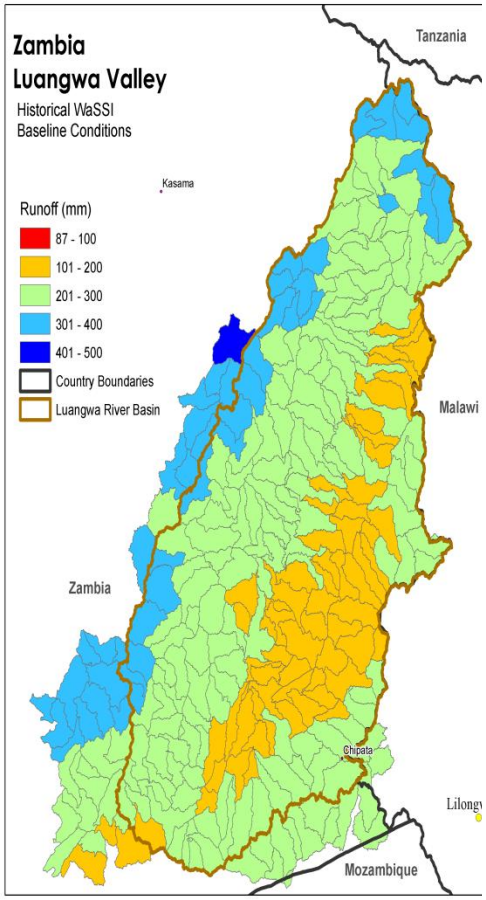

Zambia
Luangwa Valley
Historical WaSSI
Baseline Conditions
Kasama
Runoff (mm)
87 - 100
101 - 200
201 - 300
301 - 400
401 - 500
Country Boundaries
Luangwa River Basin
Tanzania
Malawi
Zambia
Chipata
Lilongwe
Mozambique

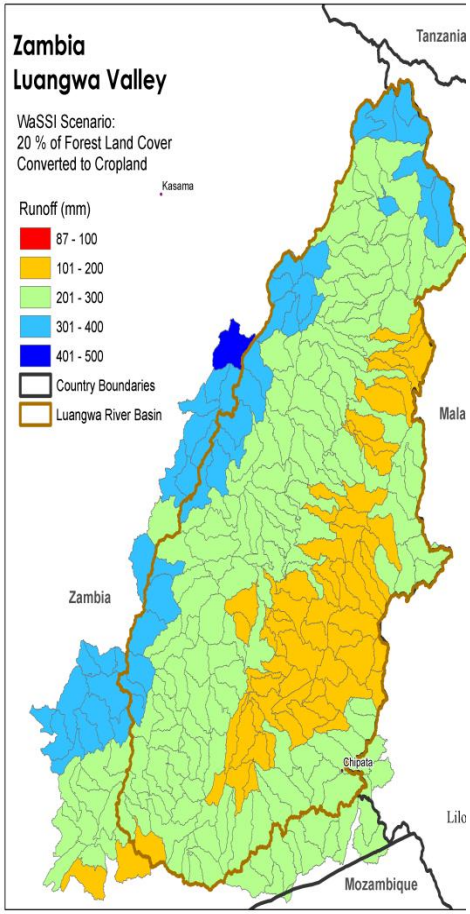

Model Validation (Zambia)
Measured
Simulated
Monthly Flow (mm)
250
200
150
100
50
0
1970
1971
1972
1972
1973
1974
1974
1975
1976
1976
1977
1978
1978
1979
1980
1980
1981
1982
1982
1983
1984
1984
1985
1986
1986
1987
1988
1988
1989
1990
1990
1991
1992
1992
1993
1994
1994
1995
1996
1996
1997
1998
1998
1999
2000
2000
2001
2002
2002
2003
2004
2004

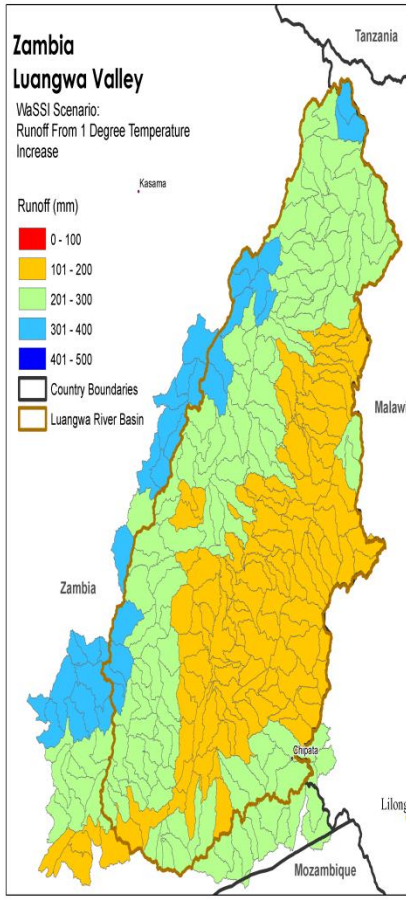

Model Validation (Zambia) (1980-1982)
Measured
Simulated
Monthly Flow (mm)
160
140
120
100
80
60
40
20
0
1980
1981
1982

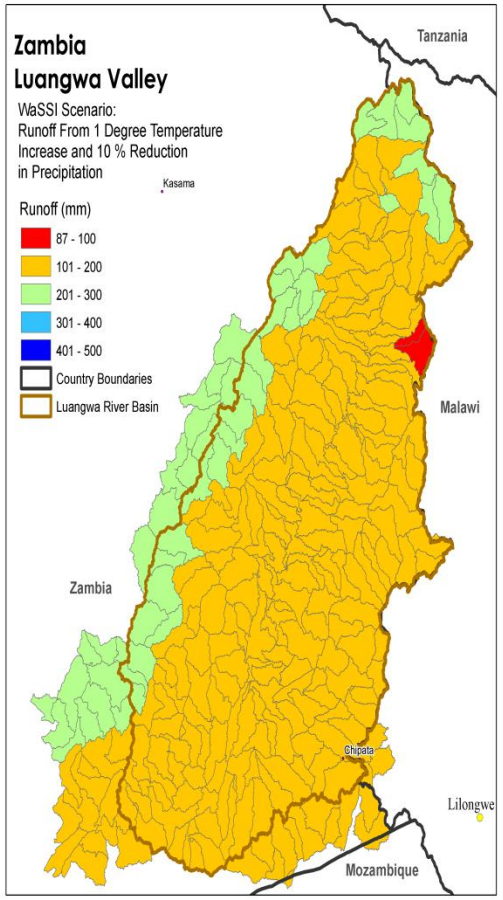

Model Validation (Zambia) (1996-2005)
Measured
Simulated
Monthly Flow (mm)
250
200
150
100
50
0
1996 1996 1997 1997 1997 1997 1997 1997 1998 1998 1998 1998 1998 1998 1999 1999 1999 1999 1999 1999 2000 2000 2000 2000 2000 2000 2001 2001 2001 2001 2001 2001 2002 2002 2002 2002 2002 2002 2003 2003 2003 2003 2003 2003 2004 2004 2004 2004 2004 2004 2005 2005

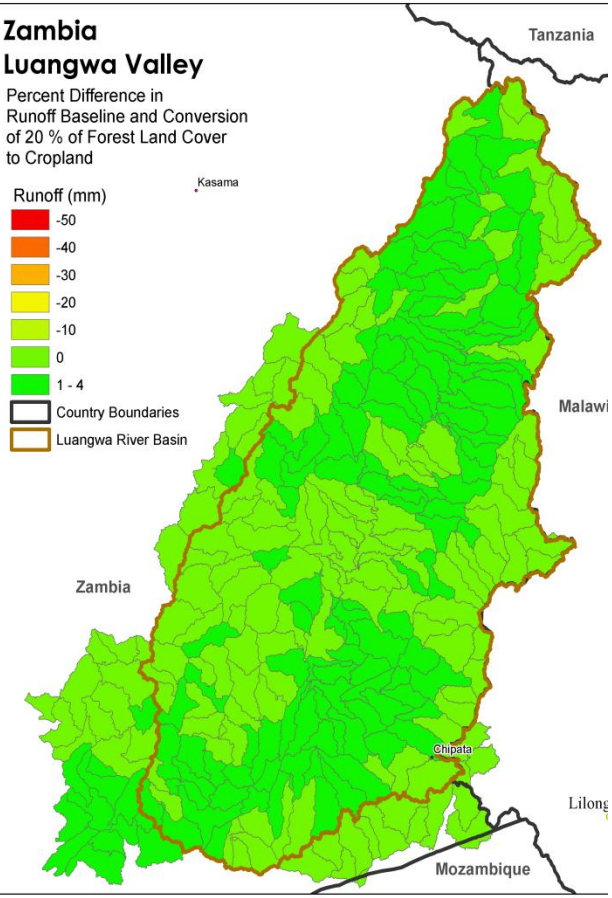
Scenarios

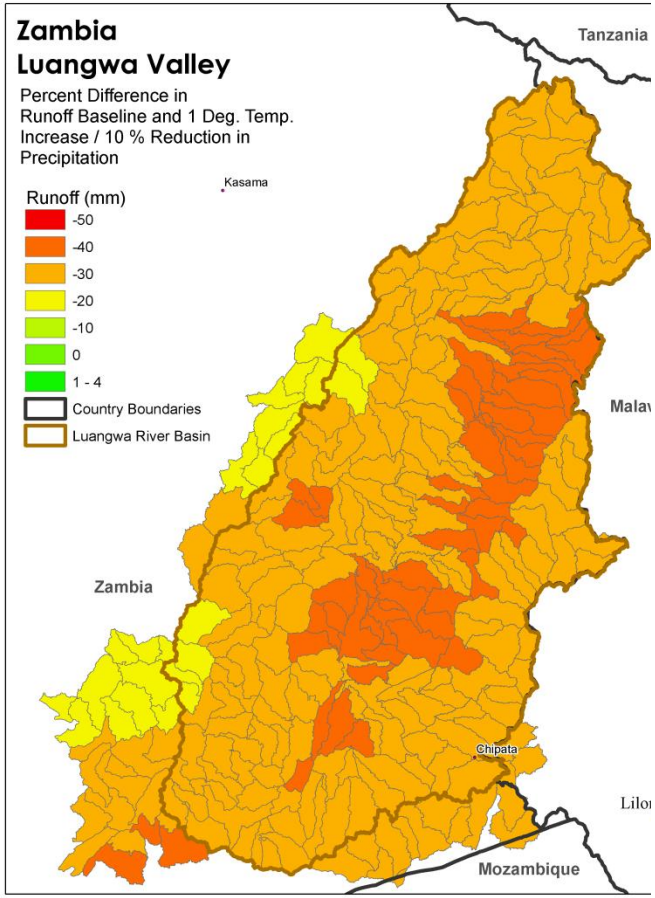

Zambia
Luangwa Valley
Historical WaSSI
Baseline Conditions
Tanzania
Kasama
Runoff (mm)
87 - 100
101 - 200
201 - 300
301 - 400
401 - 500
Country Boundaries
Luangwa River Basin
Malawi
Zambia
Chipata
Mozambique

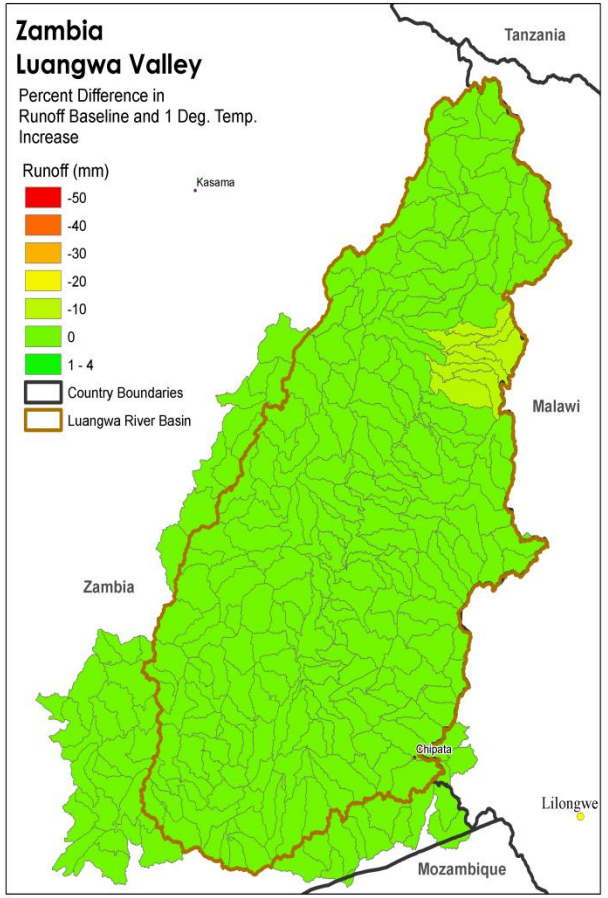

Zambia
Luangwa Valley
WaSSI Scenario:
20 % of Forest Land Cover
Converted to Cropland
Tanzania
Kasama
Runoff (mm)
87 - 100
101 - 200
201 - 300
301 - 400
401 - 500
Country Boundaries
Luangwa River Basin
Zambia
Chipata
Mozambique


Zambia
Luangwa Valley
WaSSI Scenario:
Runoff From 1 Degree Temperature
Increase
Tanzania
Kasama
Runoff (mm)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
Country Boundaries
Luangwa River Basin
Zambia
Chipata
Mozambique


Zambia
Luangwa Valley
WaSSI Scenario:
Runoff From 1 Degree Temperature
Increase and 10 % Reduction
in Precipitation
Tanzania
Kasama
Runoff (mm)
87 - 100
101 - 200
201 - 300
301 - 400
401 - 500
Country Boundaries
Luangwa River Basin
Malawi
Zambia
Chipata
Mozambique

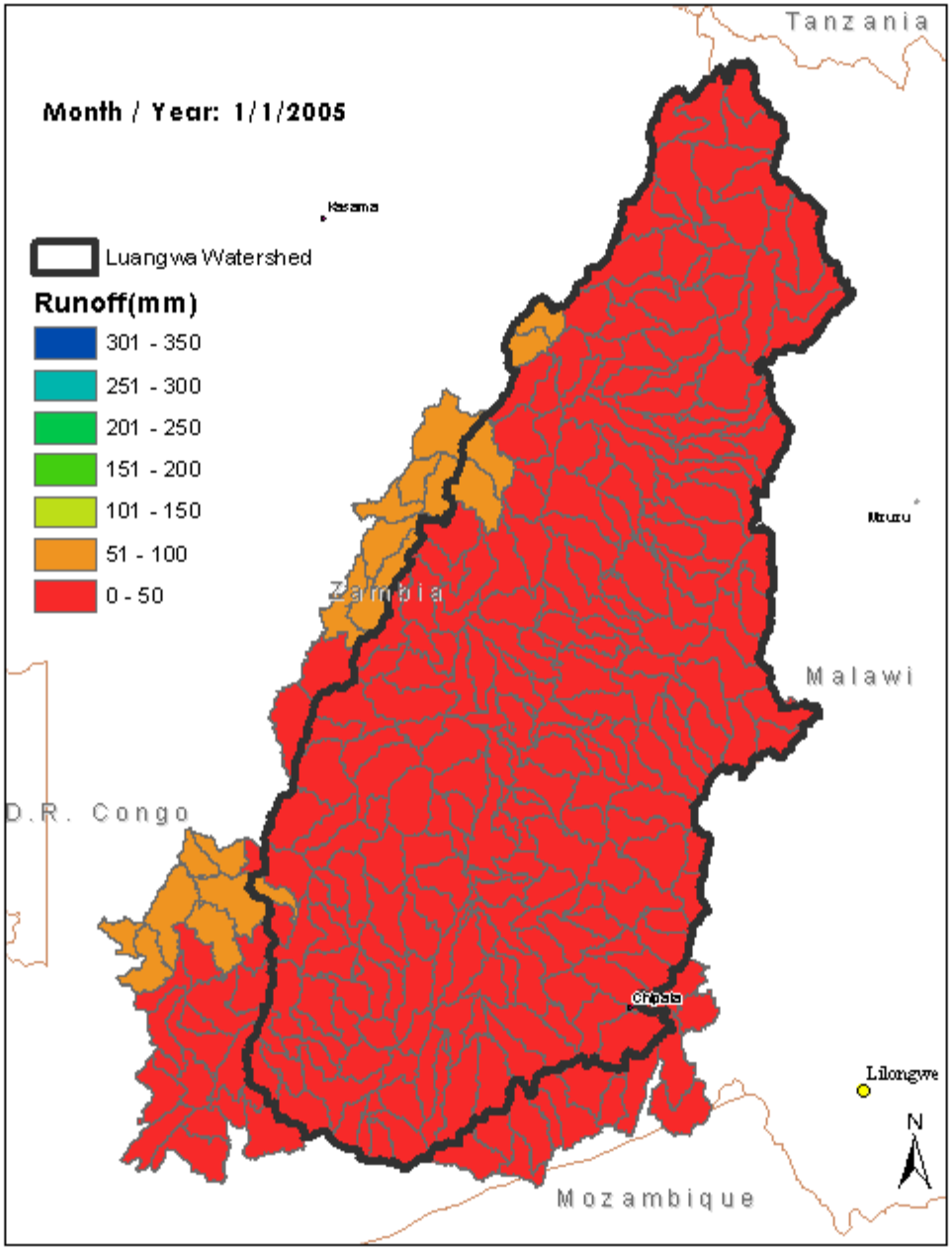

Zambia
Luangwa Valley
Percent Difference in
Runoff Baseline and Conversion
of 20 % of Forest Land Cover
to Cropland
Runoff (mm)
-50
-40
-30
-20
-10
0
1 - 4
Country Boundaries
Luangwa River Basin
Kasama
Tanzania
Malawi
Zambia
Chipata
Mozambique


Zambia
Luangwa Valley
Percent Difference in
Runoff Baseline and 1 Deg. Temp.
Increase / 10 % Reduction in
Precipitation
Runoff (mm)
-50
-40
-30
-20
-10
0
1 - 4
Country Boundaries
Luangwa River Basin
Kasama
Tanzania
Zambia
Chipata
Mozambique


Zambia
Luangwa Valley
Percent Difference in
Runoff Baseline and 1 Deg. Temp.
Increase
Runoff (mm)
-50
-40
-30
-20
-10
0
1 - 4
Country Boundaries
Luangwa River Basin
Kasama
Tanzania
Malawi
Zambia
Chipata
Mozambique

Zambia

Luangwa Valley Monthly Runoff (2005 - 2009)



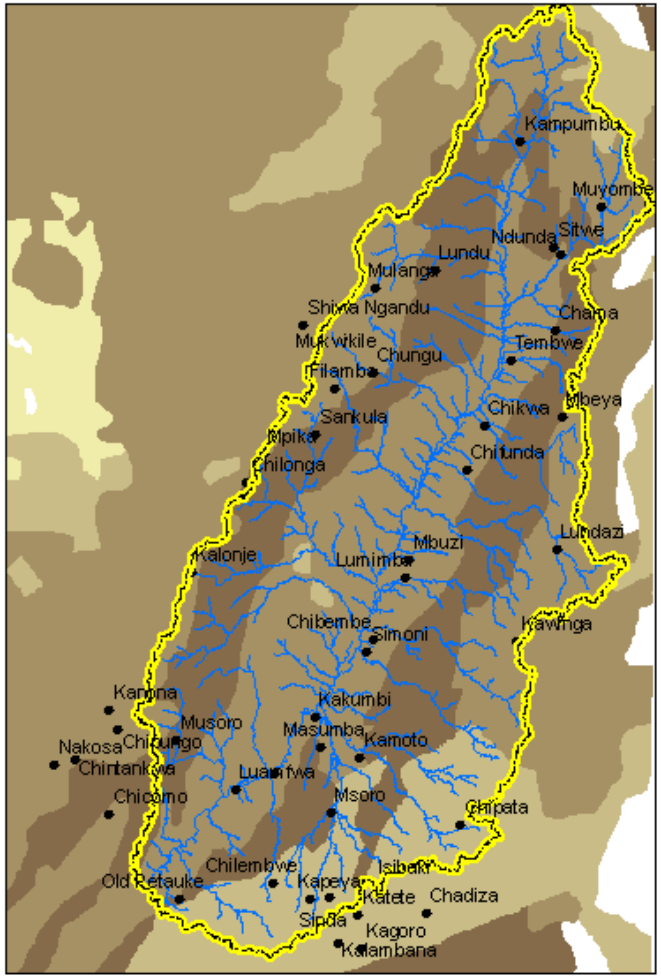
Result Scenario: Sedimentation

- Scenarios (2)
  - Baseline
    - 2009 landcover
    - Monthly precipitation and temperature from 1960-2009
  - Deforestation
    - Simulate converting one forest landcover class to crop
      - Closed (> 40%) broadleaved deciduous forest (> 5m)

Universal Soil Loss Equation

$$A = R * K * LS * C * P$$

A: Average annual soil loss (Tons/ha*yr)
R : Rainfall and runoff erosivity
K: Soil erodibility
LS: Slope length-gradient factor
C: Crop and management Factor
P: Support practice factor



Rainfall Erosivity (R)

MJ*mm/ha*h*yr

- 14,254 - 16,000
- 16,000- 18,000
- 18,000 - 20,000
- 20,000 - 22,000
- 22,000 - 25,770

• Towns

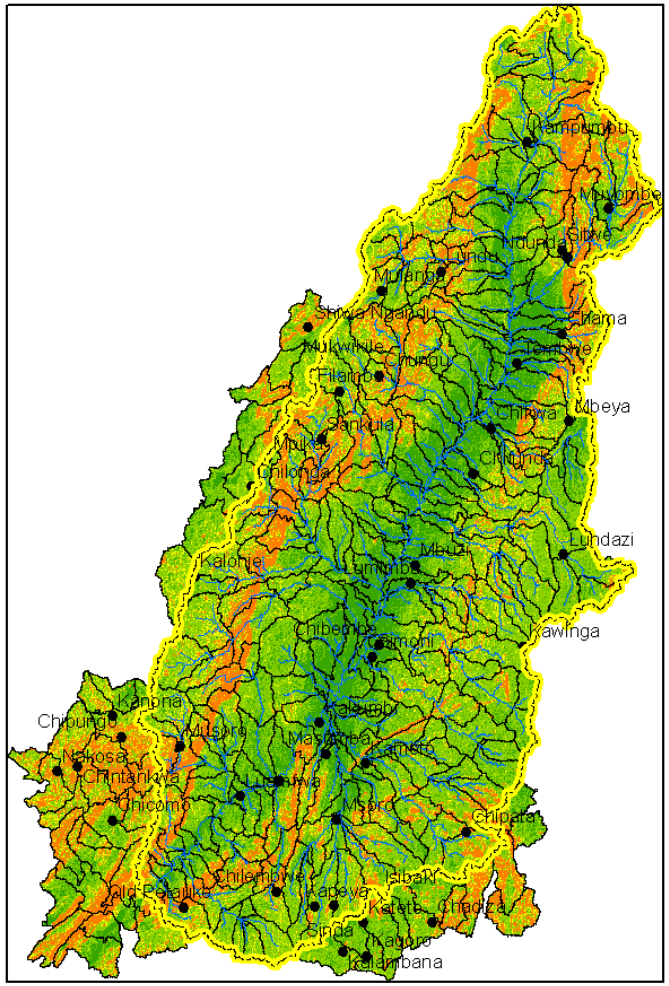
Luangwa River

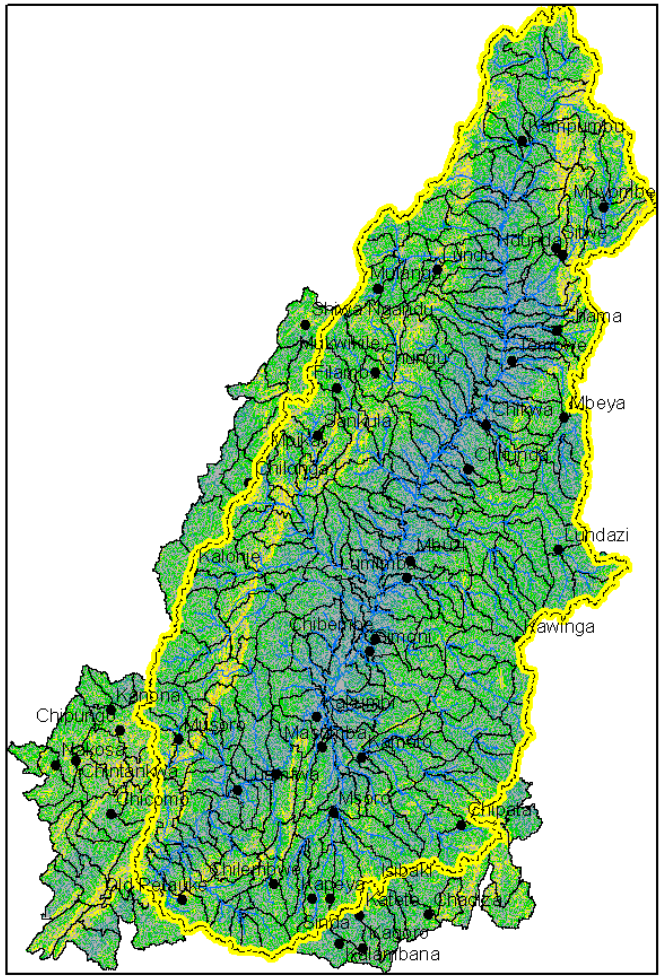
Watershed Boundary

Soil Erodibility (K)

T*ha*h/ha*MJ*mm

- 0 - 0.02
- 0.02 - 0.04
- 0.04 - 0.06
- 0.06 - 0.08
- 0.08 - 0.1





Slope

- 0% - 1%
- 1.0% - 3.5%
- 3.5% - 5%
- 5% - 75%
- 75% - 88%

- Towns
- **Luangwa River**
- Watershed Boundary

Slope Length (m)

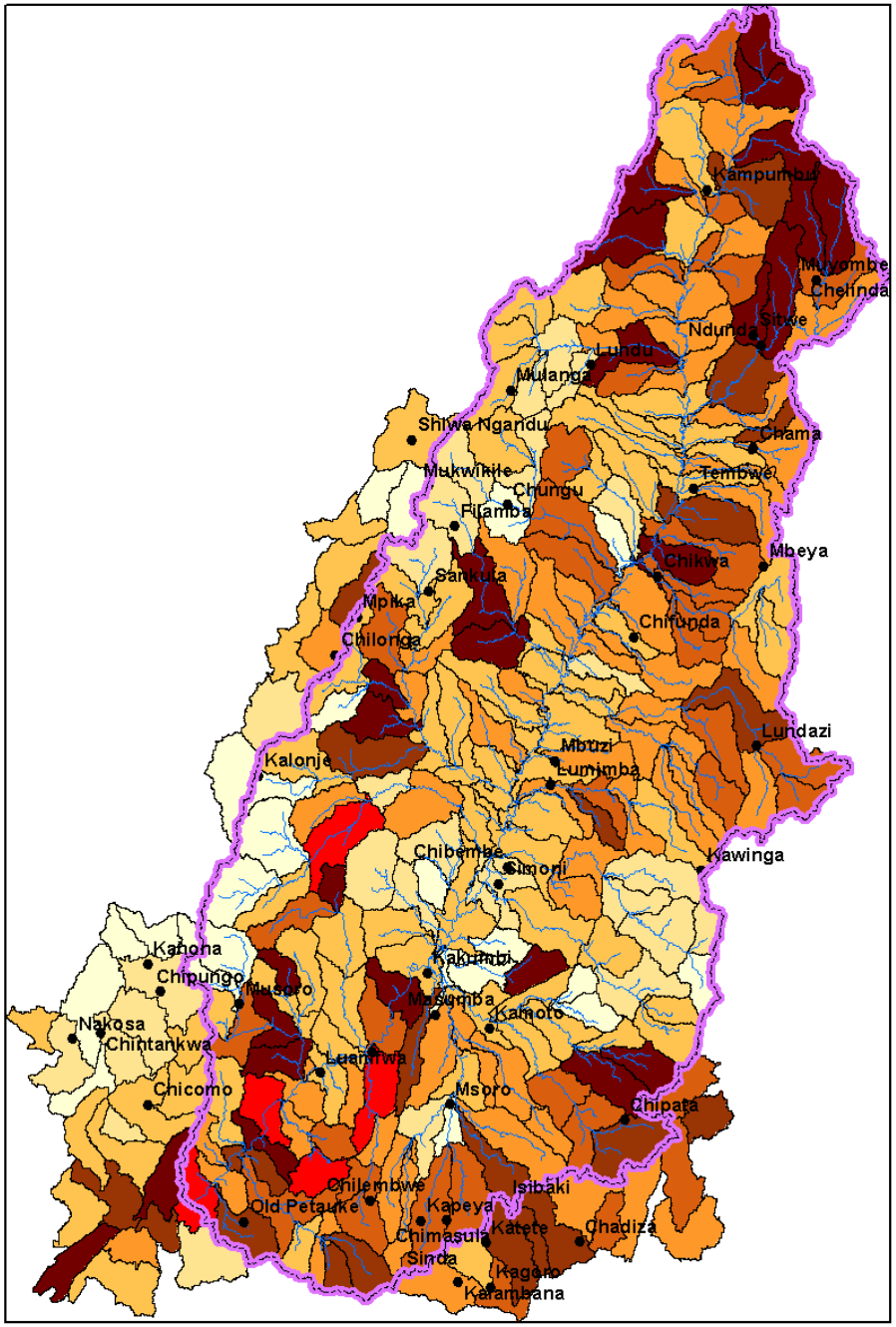
- 0
- 0 - 1
- 1 - 10
- 10 - 100
- 100 - 1,000
- 1,000 - 1,767

Cover and Management Factor(C) and Practice Factor (P)

lucode	LULC_desc	usle_c	usle_p
14	Rainfed croplands	0.07	0.5
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	0.07	0.5
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	0.1	1
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	0.001	1
50	Closed (>40%) broadleaved deciduous forest (>5m)	0.001	1
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	0.001	1
70	Closed (>40%) needleleaved evergreen forest (>5m)	0.001	1
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	0.001	1
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	0.001	1
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	0.1	1
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	0.1	1
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	0.001	1
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	0.1	1
150	Sparse (<15%) vegetation	0	1
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	0	1
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	0	1
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	0	1
190	Artificial surfaces and associated areas (Urban areas >50%)	0	1
200	Bare areas	0	1
210	Water bodies	0	1

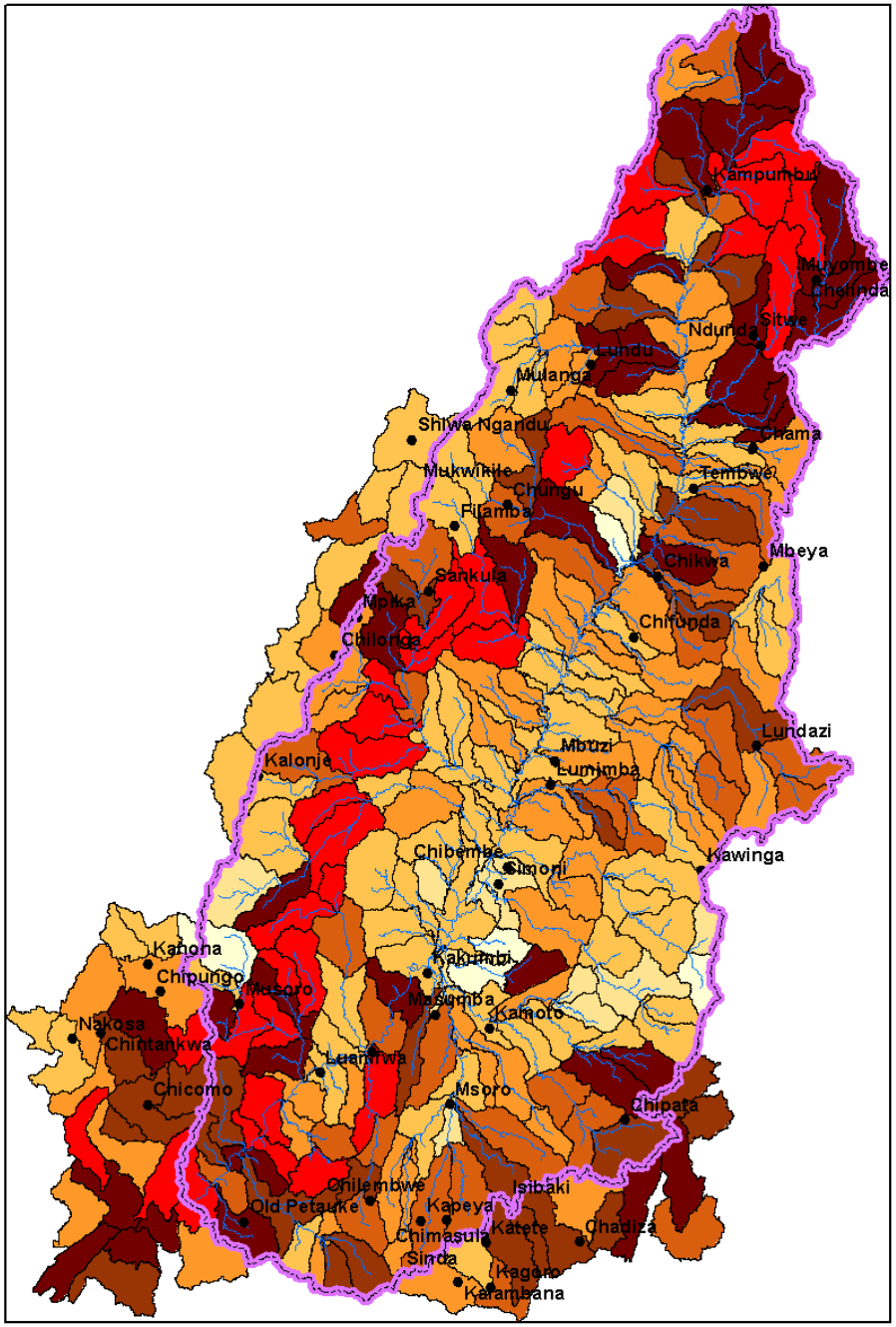
- Georgia Soil Water and Conservation Commission, 2000, Manuel for Erosion and Sediment Control in Georgia
- USLE Fact Sheet, Ontario Ministry of Agriculture Food and Rural Affairs

Universal Soil Loss Equation
Mean Potential Soil Loss
by
Watershed: Baseline



Watershed Boundary	30 - 60
Tons/ha	60 - 90
1.6 - 5	90 - 120
5 - 10	120 - 220
10 - 30	220 - 374

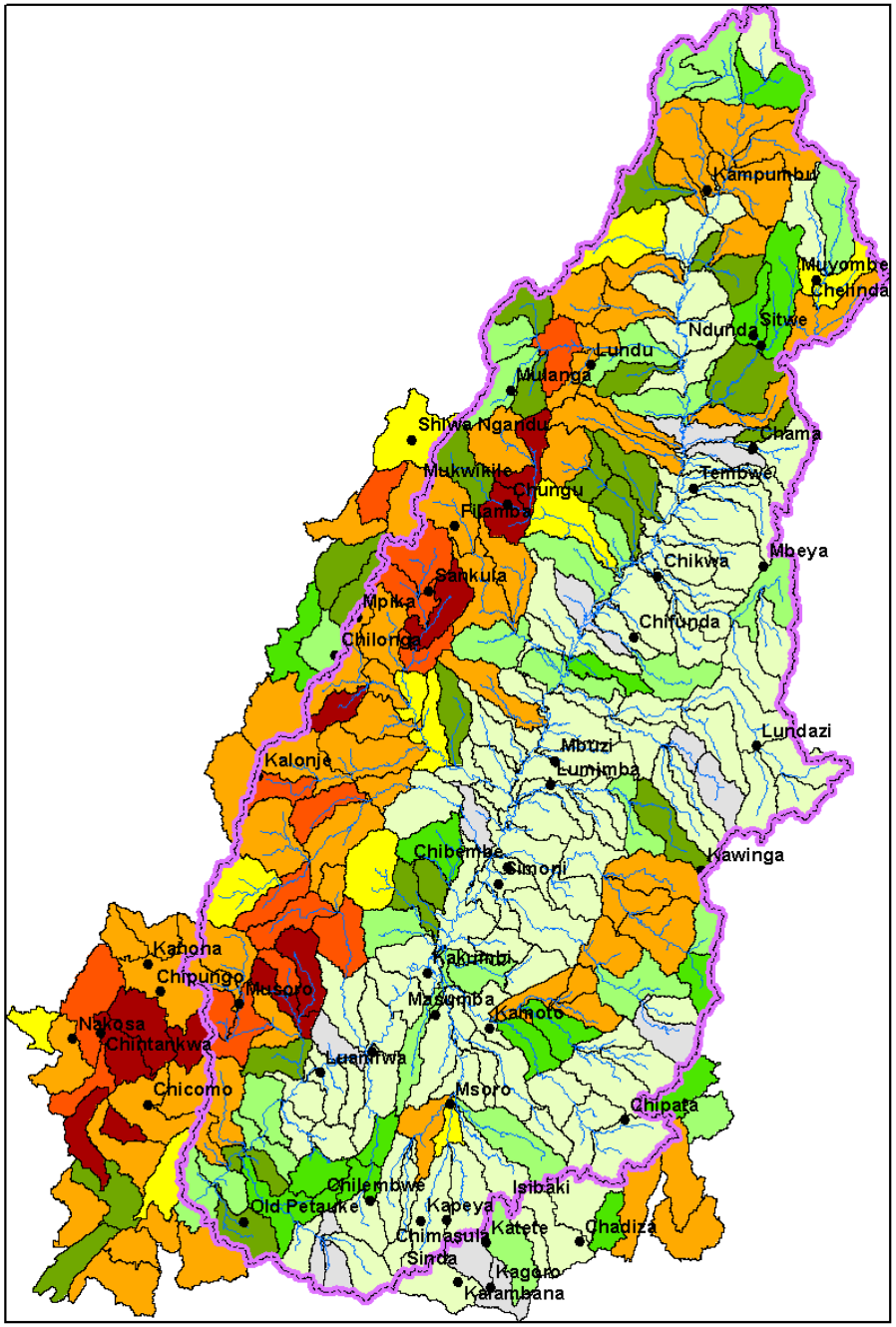
Universal Soil Loss Equation
Mean Potential Soil Loss
by
Watershed: Deforestation



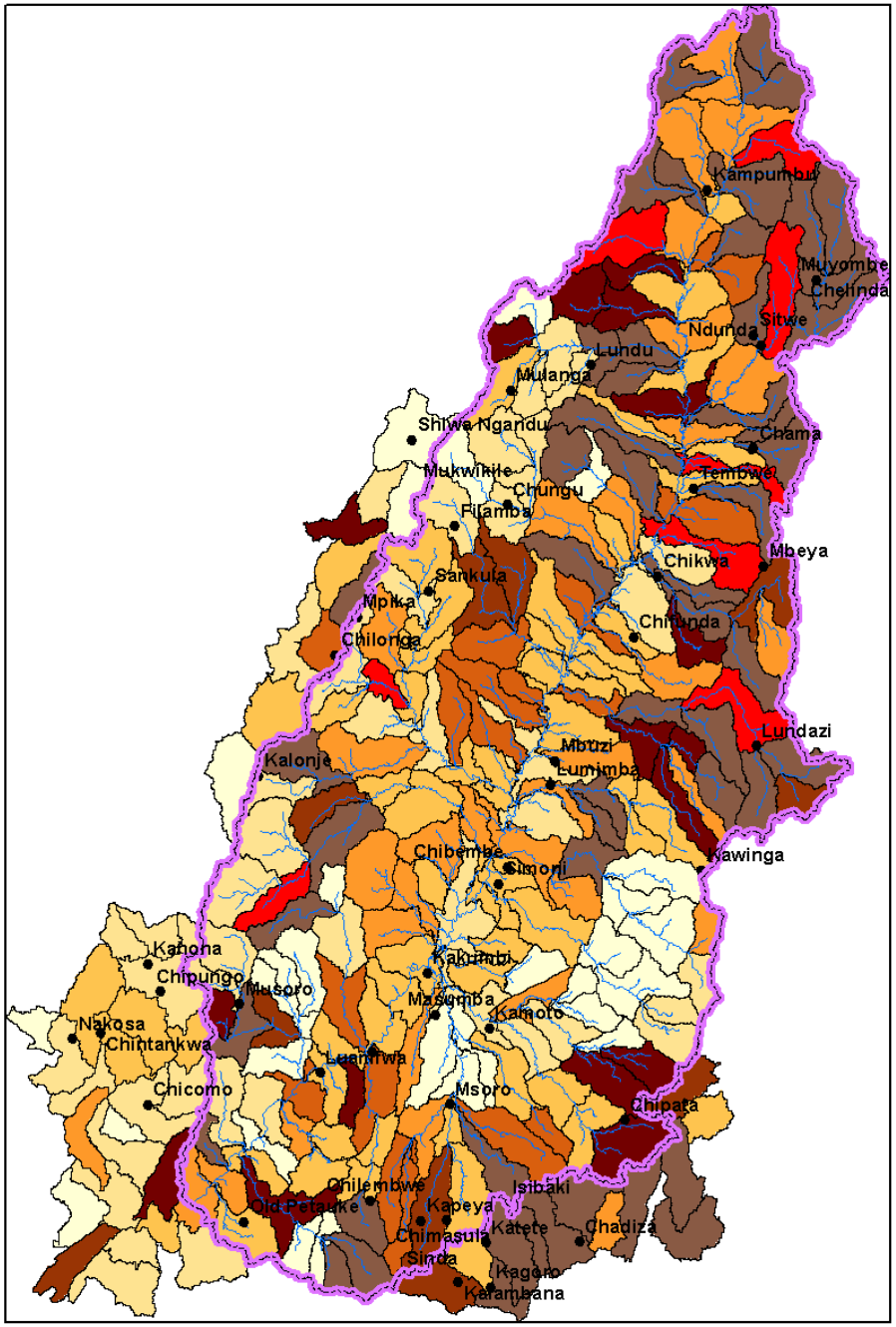
Watershed Boundary	30 - 60
Tons/ha	60 - 90
1.9 - 5	90 - 120
5 - 10	120 - 220
10 - 30	220 - 855

Universal Soil Loss Equation Potential Soil Loss by Watershed: Percent Difference

- Watershed Boundary
- 0%
- 0% - 10%
- 10% - 30%
- 30% - 50%
- 50% - 70%
- 70% - 100%
- 100% - 500%
- 500% - 1000%
- 1000% - 1509%



Mean Sediment Exported by Watershed: Baseline

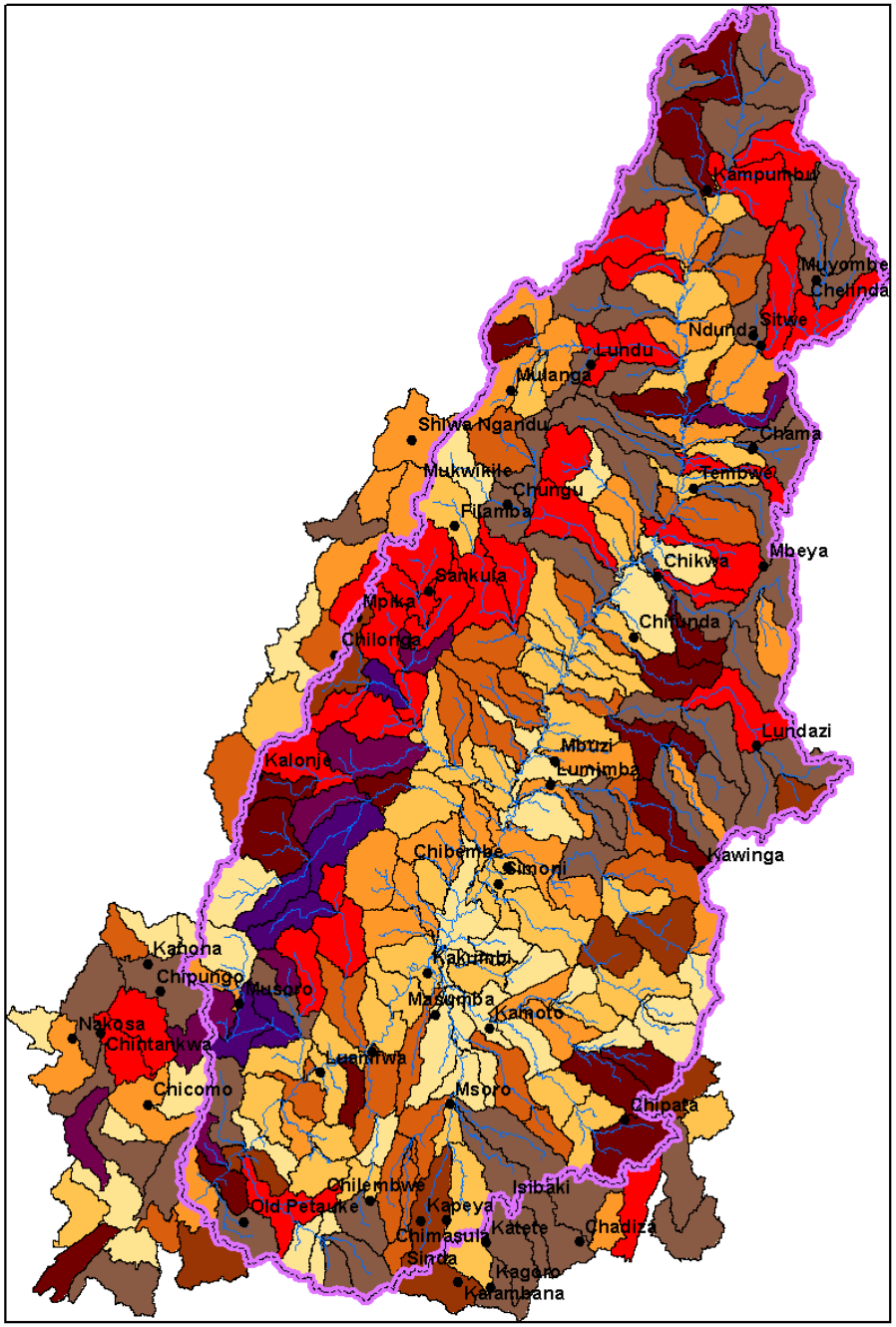


Watershed Boundary

Tons/ha

- 0 - 0.1
- 0.2 - 0.3
- 0.3 - 0.6
- 0.6 -0.9
- 0.9 - 1.2
- 1.2 - 1.5
- 1.5 - 2
- 2 - 6
- 6 - 16

Mean Sediment Exported by Watershed: Deforestation

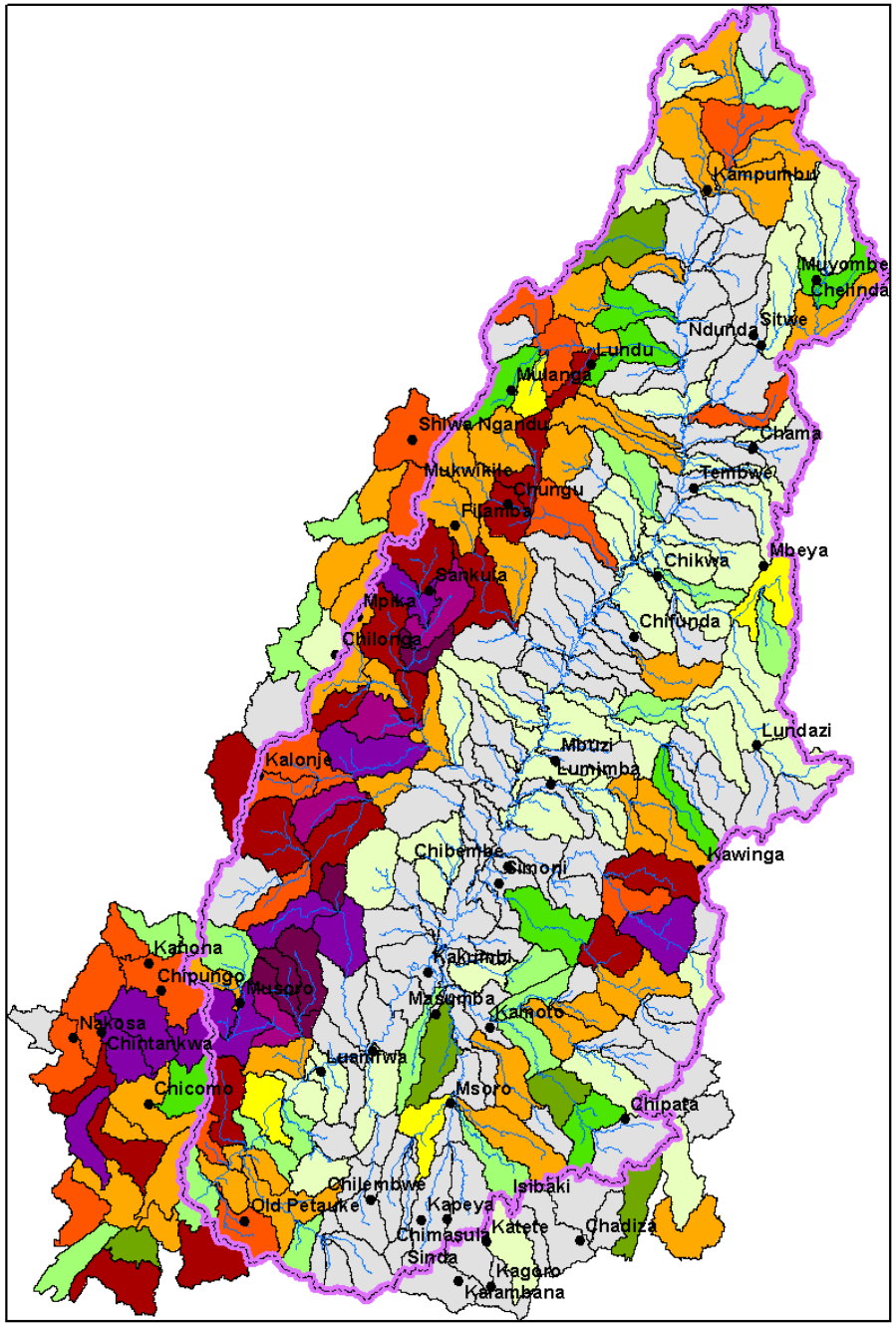


Watershed Boundary

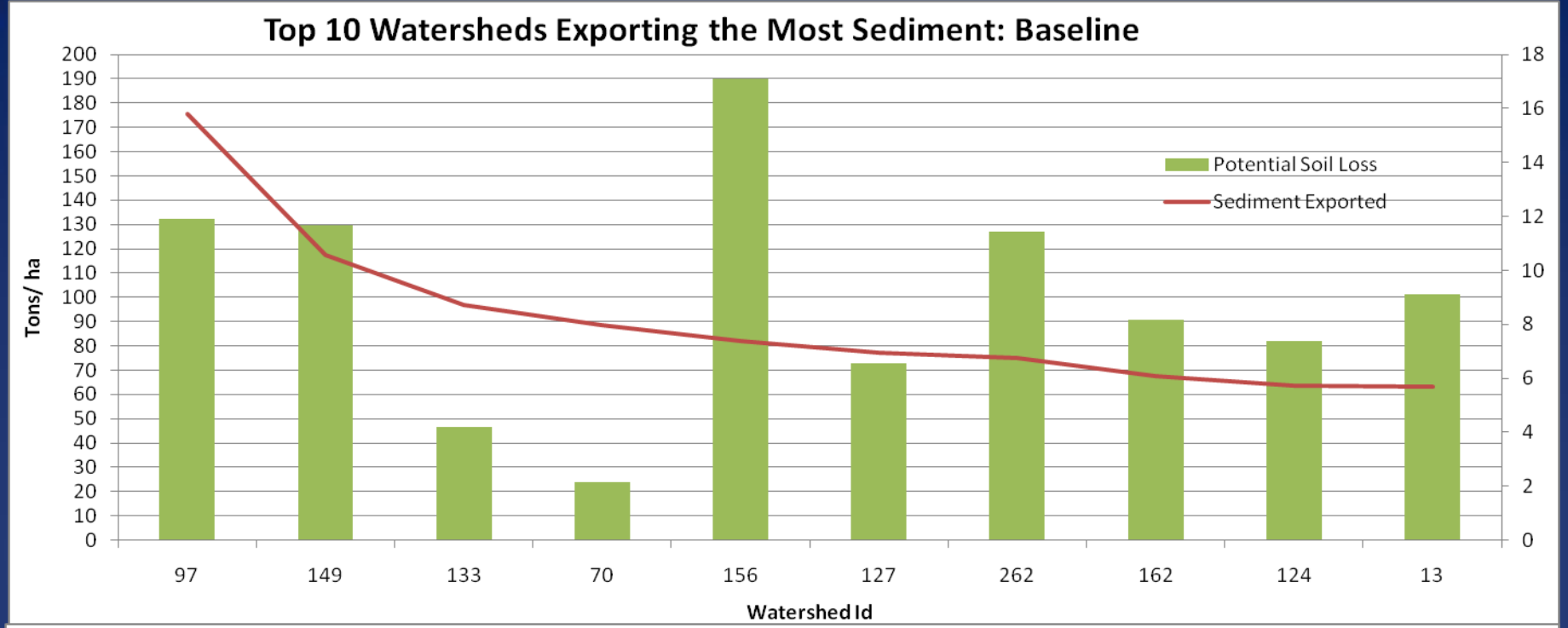
Tons/ha

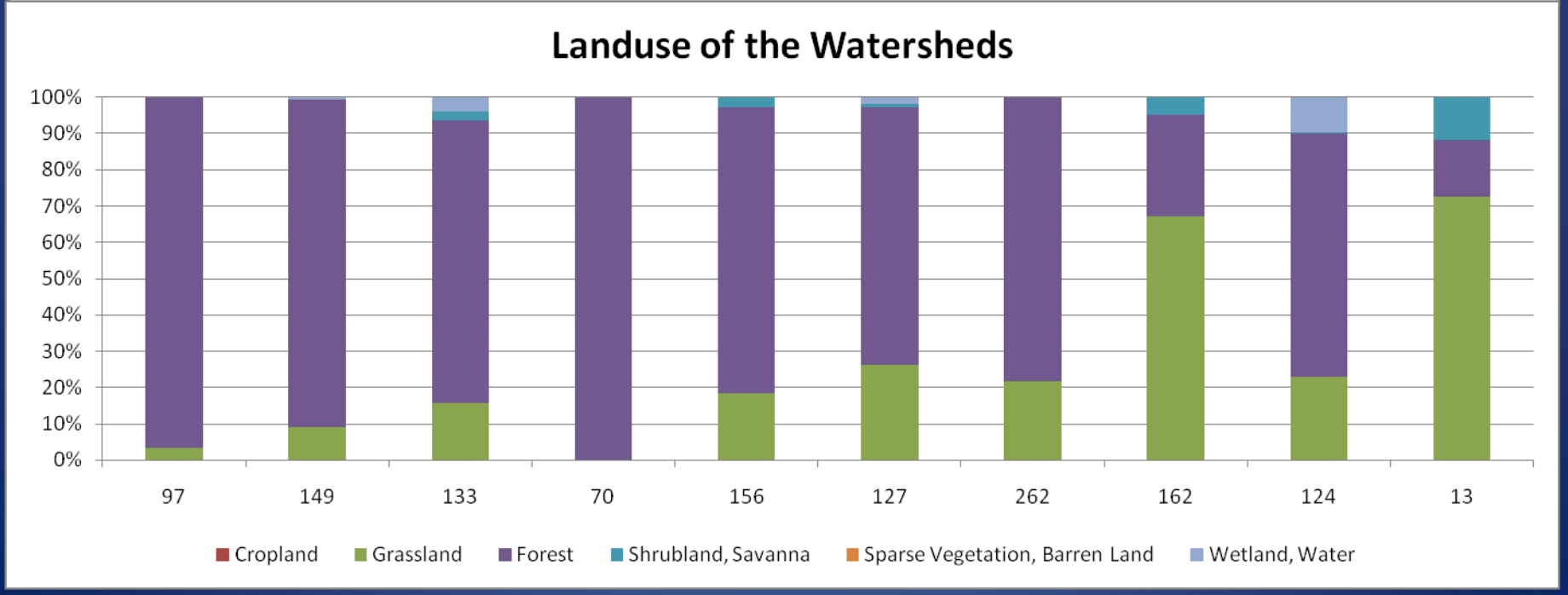
- 0.1 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- 1.2 - 1.5
- 1.5 - 2
- 2 - 6
- 6 - 20
- 20 - 70
- 70 - 144

Sediment Exported by Watershed: Percent Difference

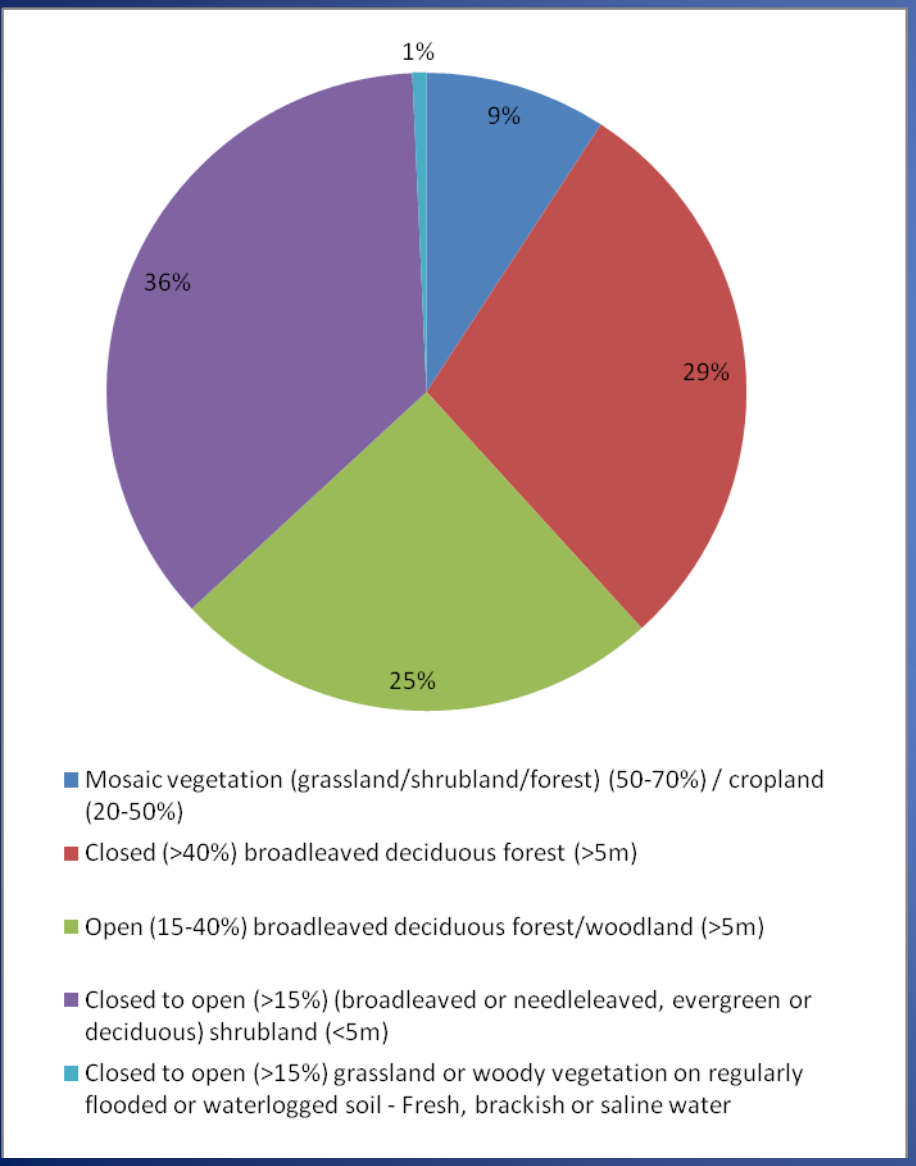


- Watershed Boundary
- 0%
- 0% - 10%
- 10% - 30%
- 30% - 50%
- 50% - 70%
- 70% - 100%
- 100% - 500%
- 500% - 1000%
- 1000% - 3000%
- 3000% - 5000%
- 5000% - 7000%
- 7000% - 69348%


Top 10 Watersheds Exporting the Most Sediment: Baseline
Tons/ ha
Potential Soil Loss
Sediment Exported
97
149
133
70
156
127
262
162
124
13
Watershed Id


Landuse of the Watersheds
97
149
133
70
156
127
262
162
124
13
Cropland
Grassland
Forest
Shrubland, Savanna
Sparse Vegetation, Barren Land
Wetland, Water

Deforestation Scenario



	Baseline	Deforestation	Percent Difference
Watershed Id	149	149	
Mean Sediment Export (Tons/ha)	10.5	16.1	53%
Mean Potential Soil Loss (Tons/ha)	129	250	94%
Mean Slope (%)	7.7	7.7	
Mean Slope Length (m)	7	7	
Mean Soil Erodibility (MJ*mm)/ (ha*h*yr)	0.068	0.068	
Mean Rainfall Erosivity (T* ha*h) / (ha*MJ*mm)	19771	19771	
C Factor (deciduous forest)	0.001	0.07	
P Factor (deciduous forest)	1	0.5	

Summary of Results

- Increases in air temperature and decreases in Precipitation will decrease stream flow
- Conversion of forest to crop land will have minimal impact on stream flow given current know of leaf area change
- Deforestation greatly increases both soil erosion and sedimentation
- There was no statistically significant relationship between time and flow

Recommendations

(good for a grad student dissertation or thesis)

- Confirm differences in leaf area due to forest conversion
  - Will impact both water yield and erosion
- Compare predicted trends in historic run-off with measured values where they exist.
- Use validated model to examine potential extremes (and reoccurrence) of low flow given alternative scenarios