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)

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Ecosystem Services Modeling Workshop: WaSSI-CB

Steve McNulty, Ge Sun, Erika Cohen, and Matt Wingard

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

August 20-27, 2010, Raleigh, NC

Outline

- Model Overview (Ge Sun)
- WaSSI-CB Model Theories (Ge Sun)
- Databases, Model Inputs and Outputs (Erika Cohen/ Matt Wingard)
- Model Application Examples (Ge Sun)

Background-Why WaSSI-CB

- Ecosystem services are critical to our lives;
- Ecosystem services are threatened by climate change, human influences (i.e. population growth), water shortages, air pollution;
- Quantify Ecosystem Service Payment Schemes;
- Water, Carbon, and Biodiversity are linked; integrated models are the best way for regional assessments
- Forest Service Cares about water, carbon, and climate change;

Drought-Induced Reduction in Global Terrestrial Net Primary Production from 2000 Through 2009

Maosheng Zhao* and Steven W. Running

20 AUGUST 2010 VOL 329 **SCIENCE** www.sciencemag.org

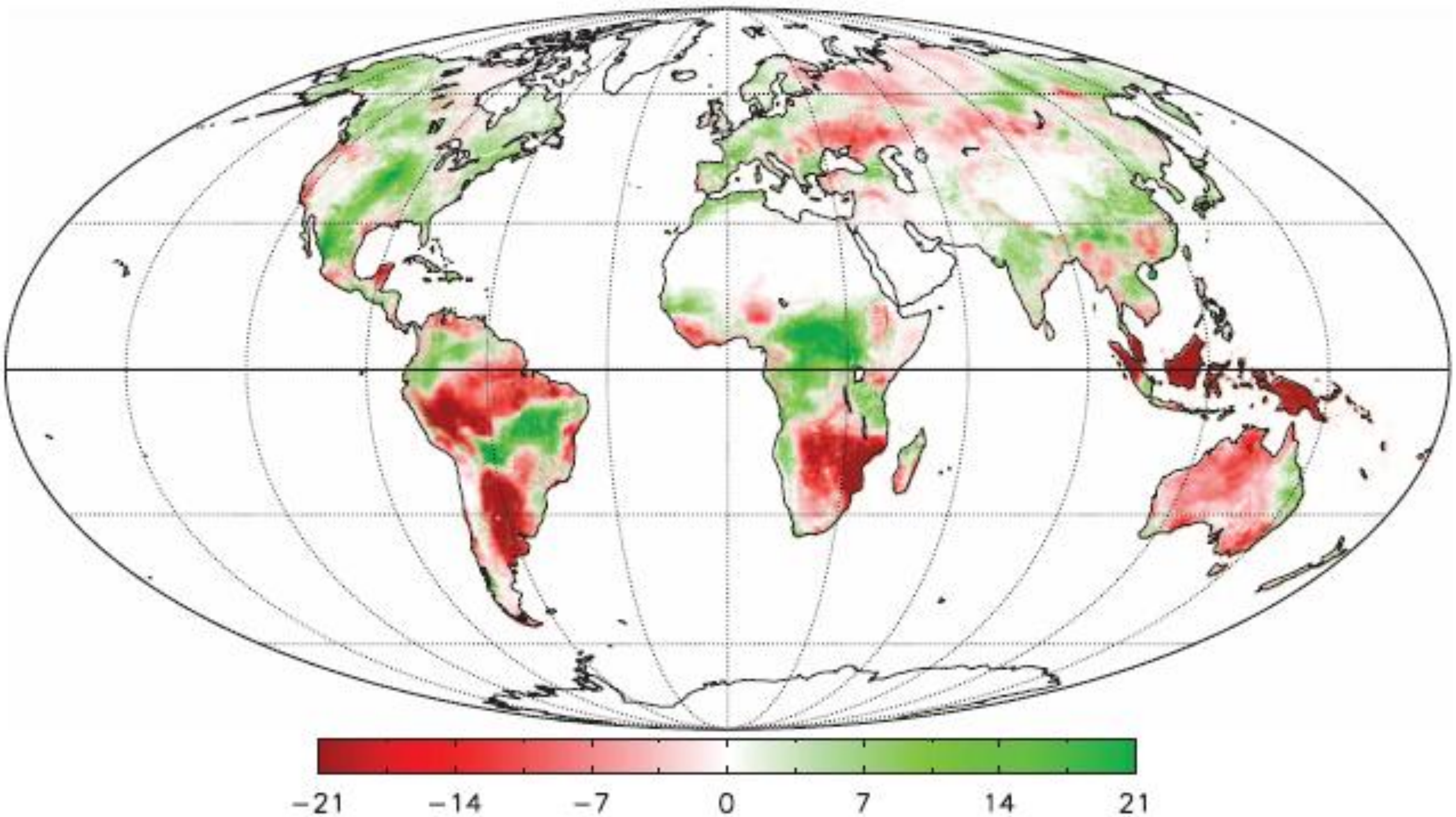
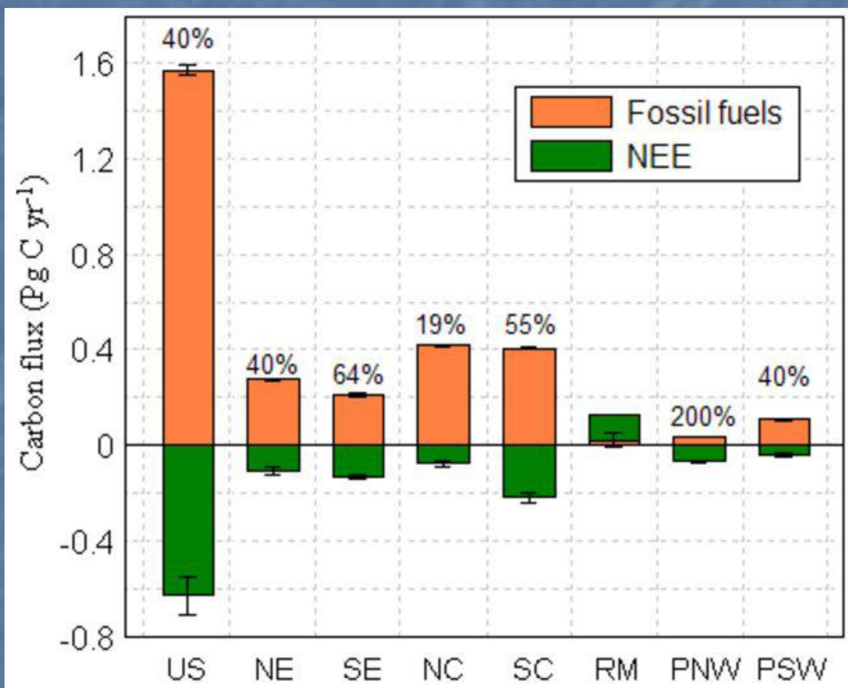


Fig. 2. Spatial pattern of terrestrial NPP linear trends from 2000 through 2009 (SOM text S1) (*8*, *10*).

Uncertainty of Ecosystem Carbon Sequestration



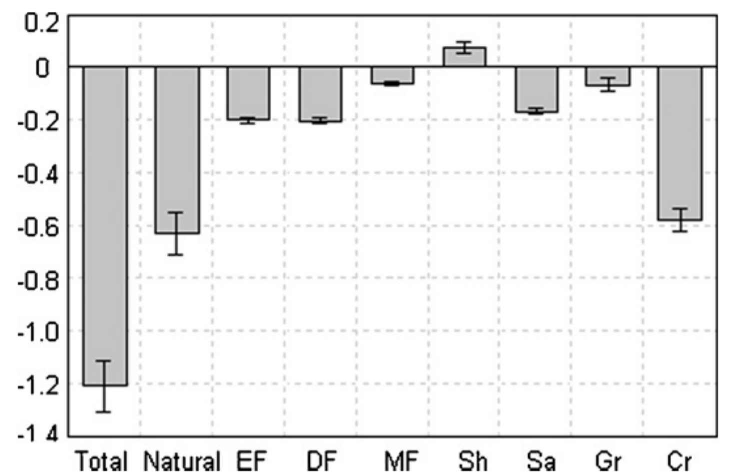
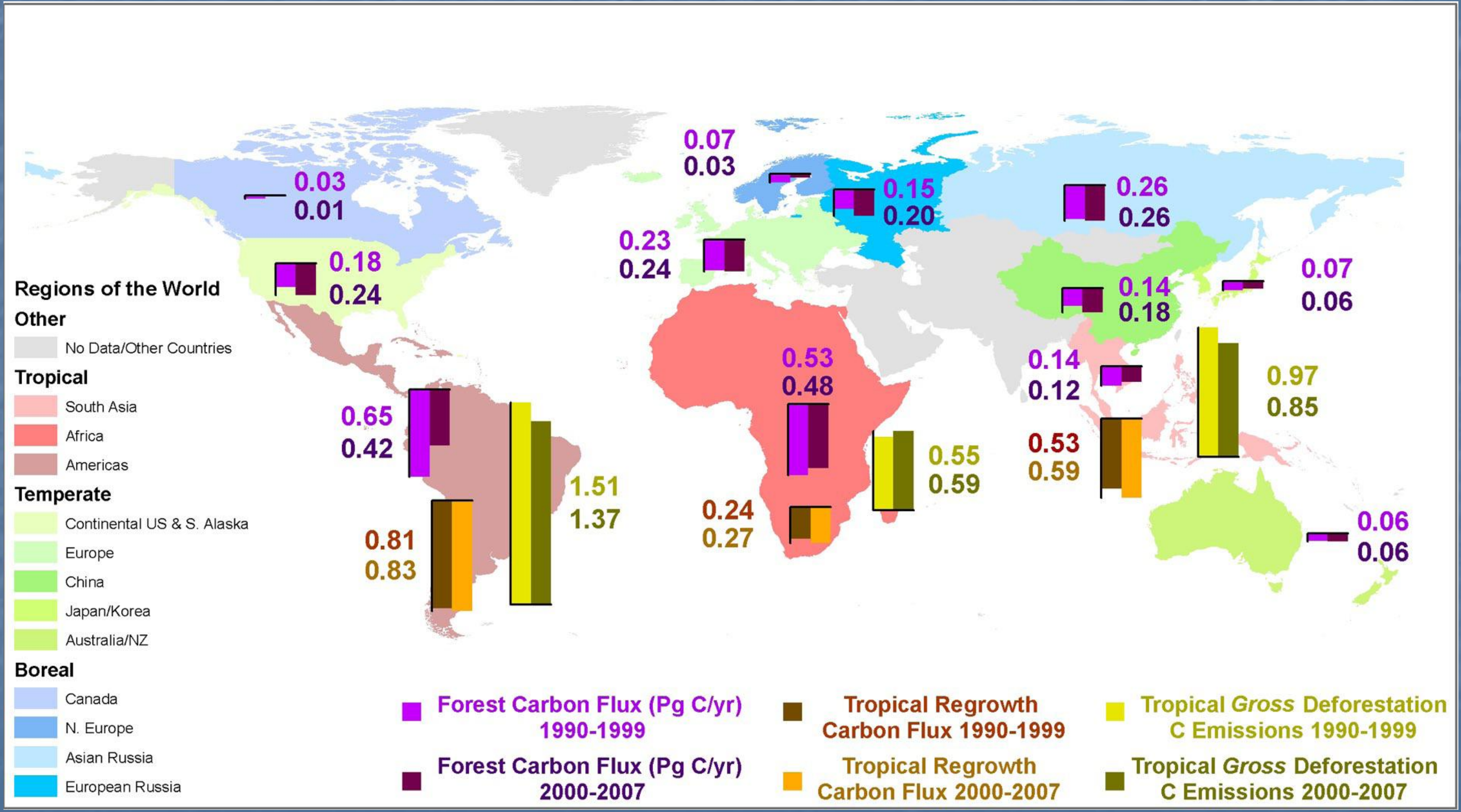


Fig. 6. Mean annual NEE for each vegetation type within the conterminous U.S. over the period 2001–2006: evergreen forests (EF), deciduous forests (DF), mixed forests (MF), shrublands (Sh), savannas (Sa), and grasslands (Gr). Units are pg C yr^{-1}. The bars are the estimated mean annual NEE. The error bars indicate the standard deviation from the mean.

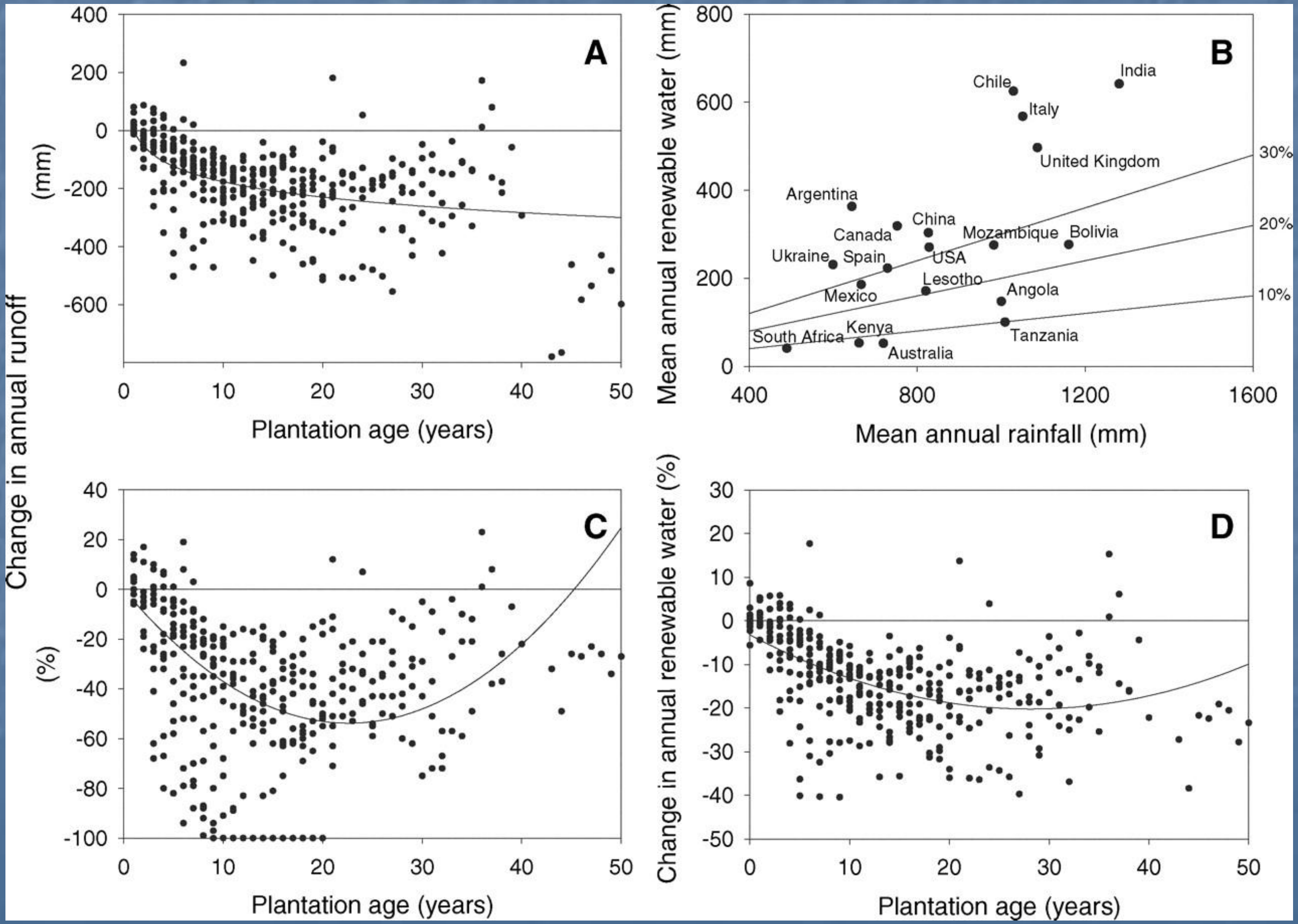
- *Xiao et al. 2011. Agricultural and Forest Meteorology*

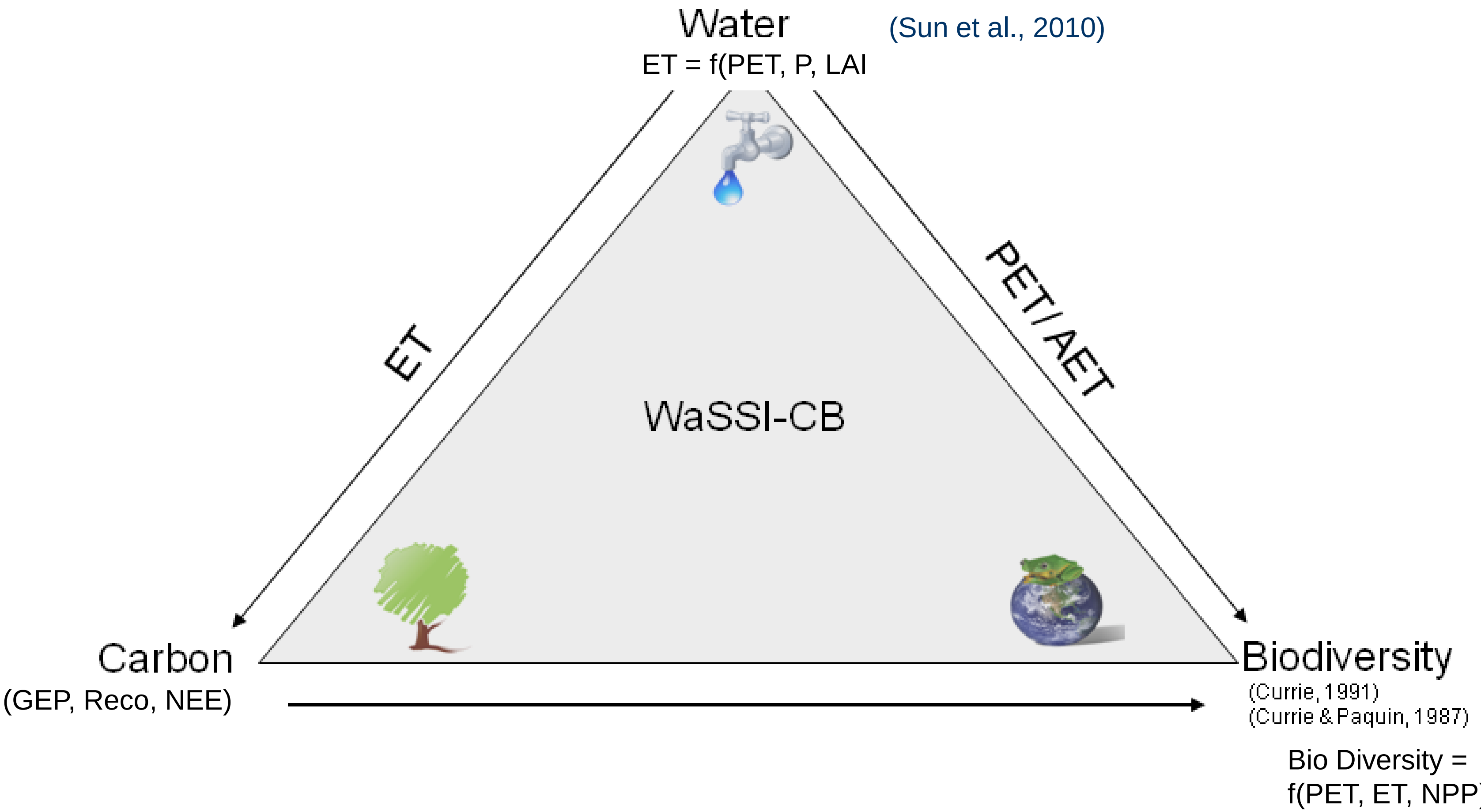
A Large and Persistent Carbon Sink in the World's Forests *(Pan et al., Science, 2011)*



Trading Water for Carbon with Biological Carbon Sequestration

Robert B. Jackson,[1*] Esteban G. Jobbágy,[1,2] Roni Avissar,[3] Somnath Baidya Roy,[3] Damian J. Barrett,[4] Charles W. Cook,[1] Kathleen A. Farley,[1] David C. le Maitre,[5] Bruce A. McCarl,[6] Brian C. Murray[7]

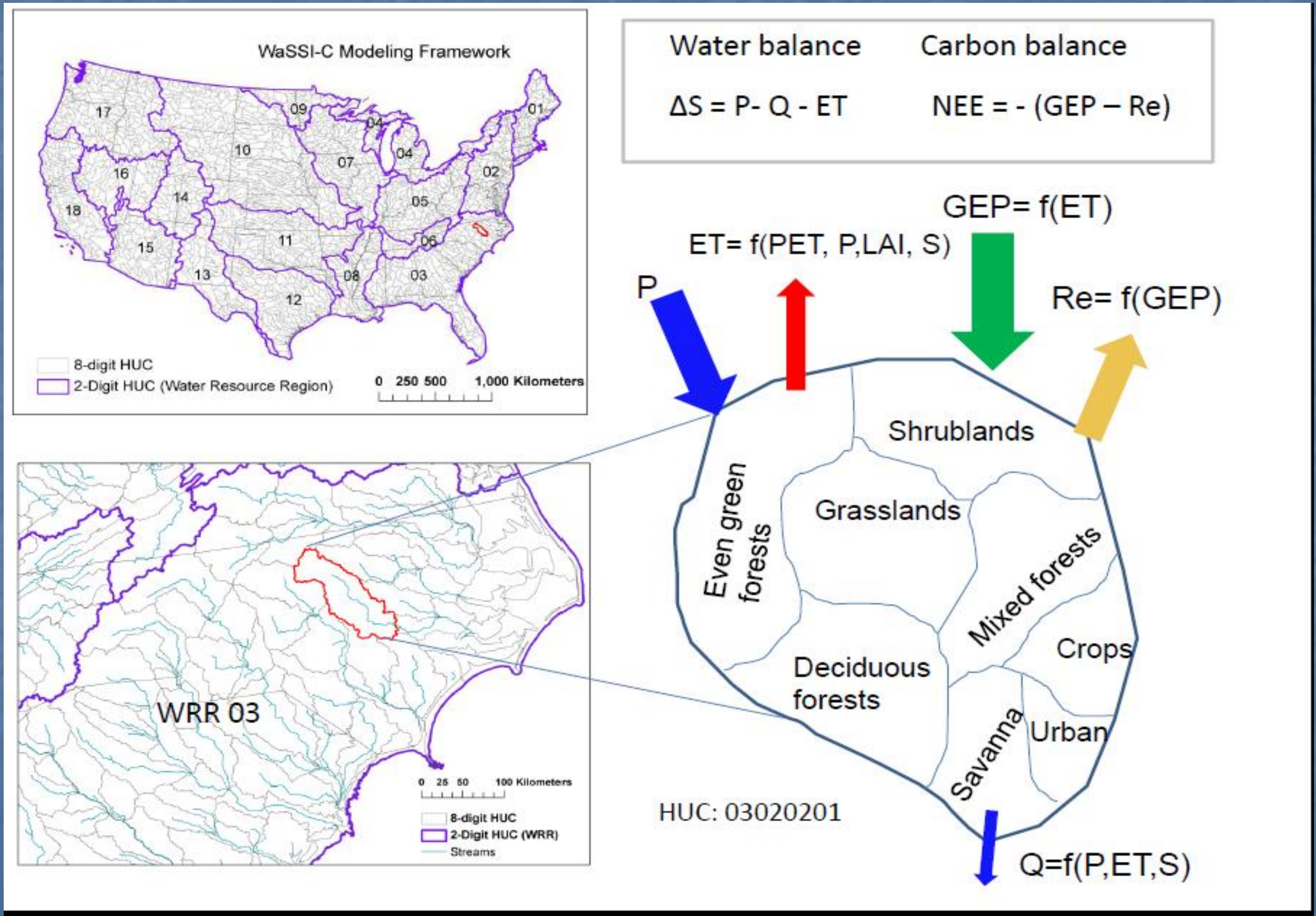




WaSSI-CB Modeling Framework

Model Framework

(Sun et al. 2011. JGR Vol 116)



Model Development: Water

Monthly Water Balances

Water Yield =
Precipitation – Evapotranspiraton - ΔS

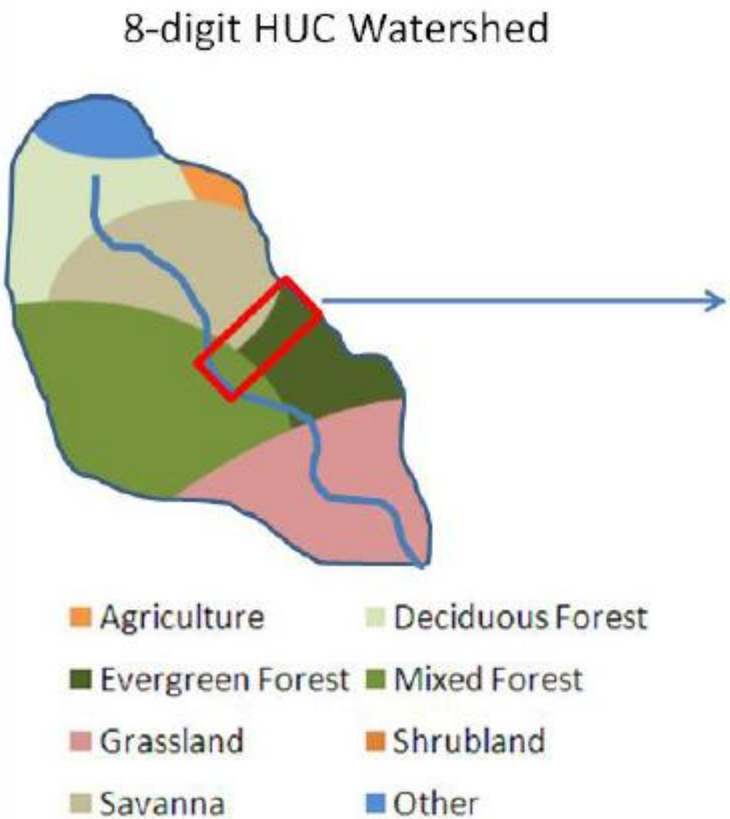
Example: In Kigali, Rwanda

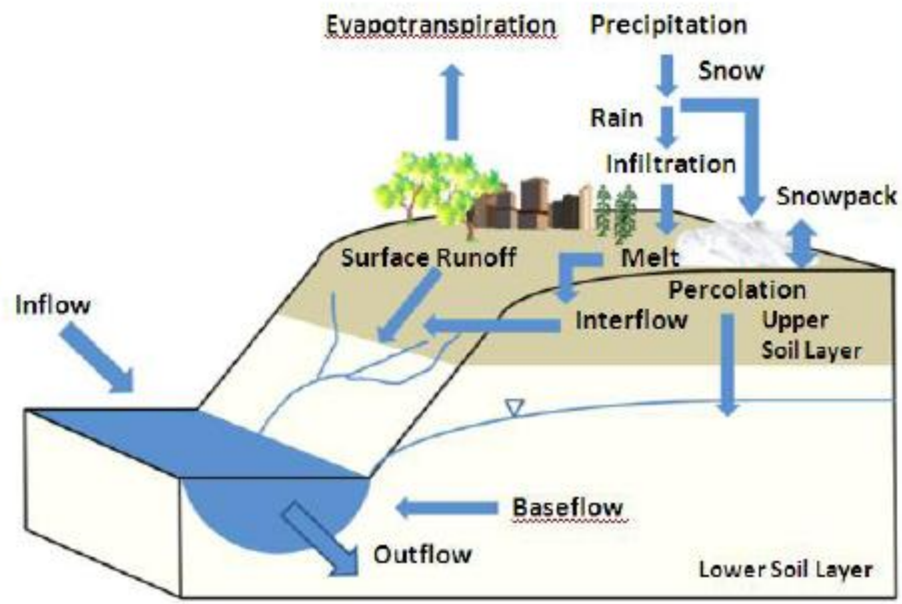
P = 1000 mm/yr; ET = 800 mm/yr.

Q = 1000-800 = 200 mm/yr.

Q/P= 20%

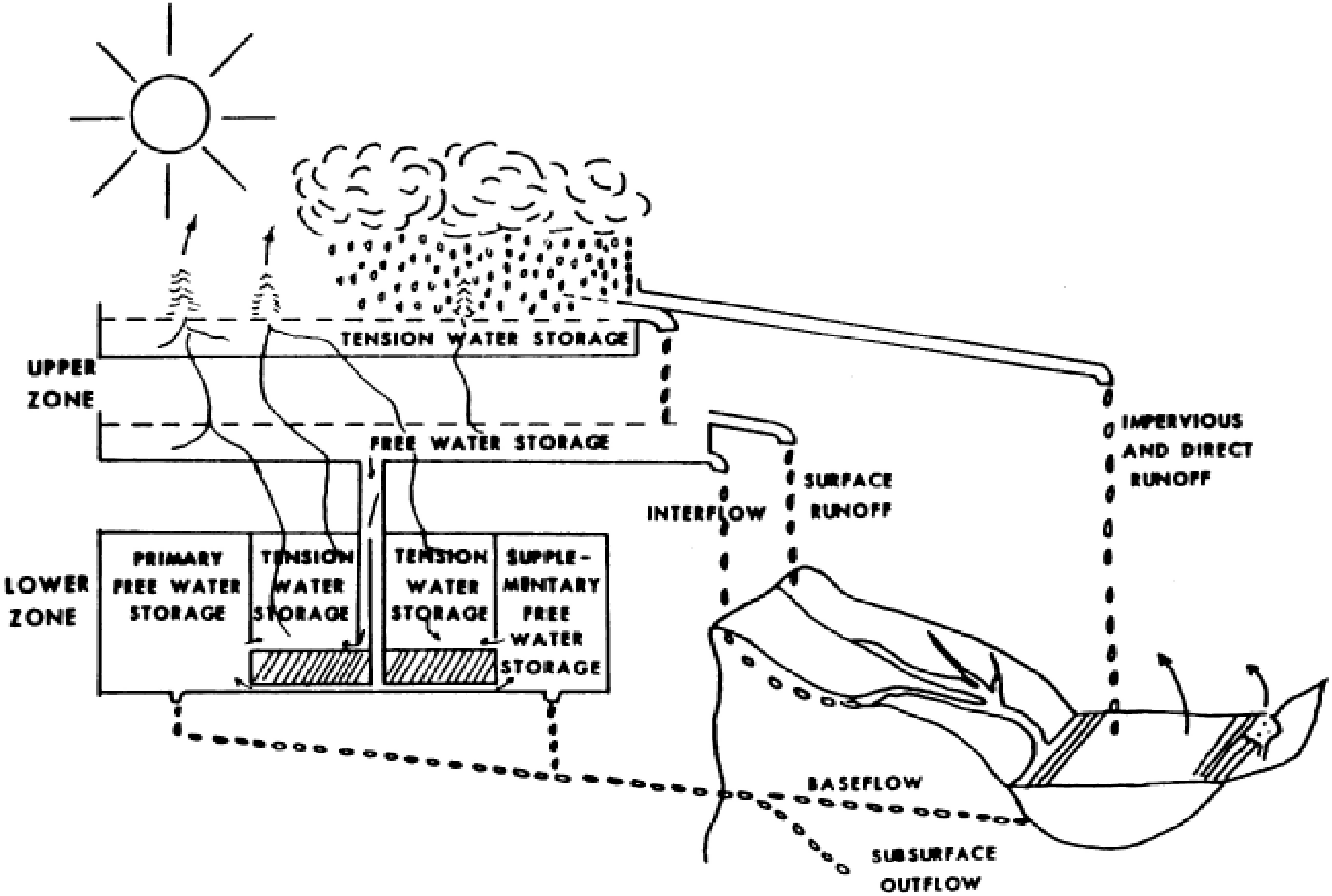
Watershed Water Balance





$$\Delta S = PPT - ET - Q$$

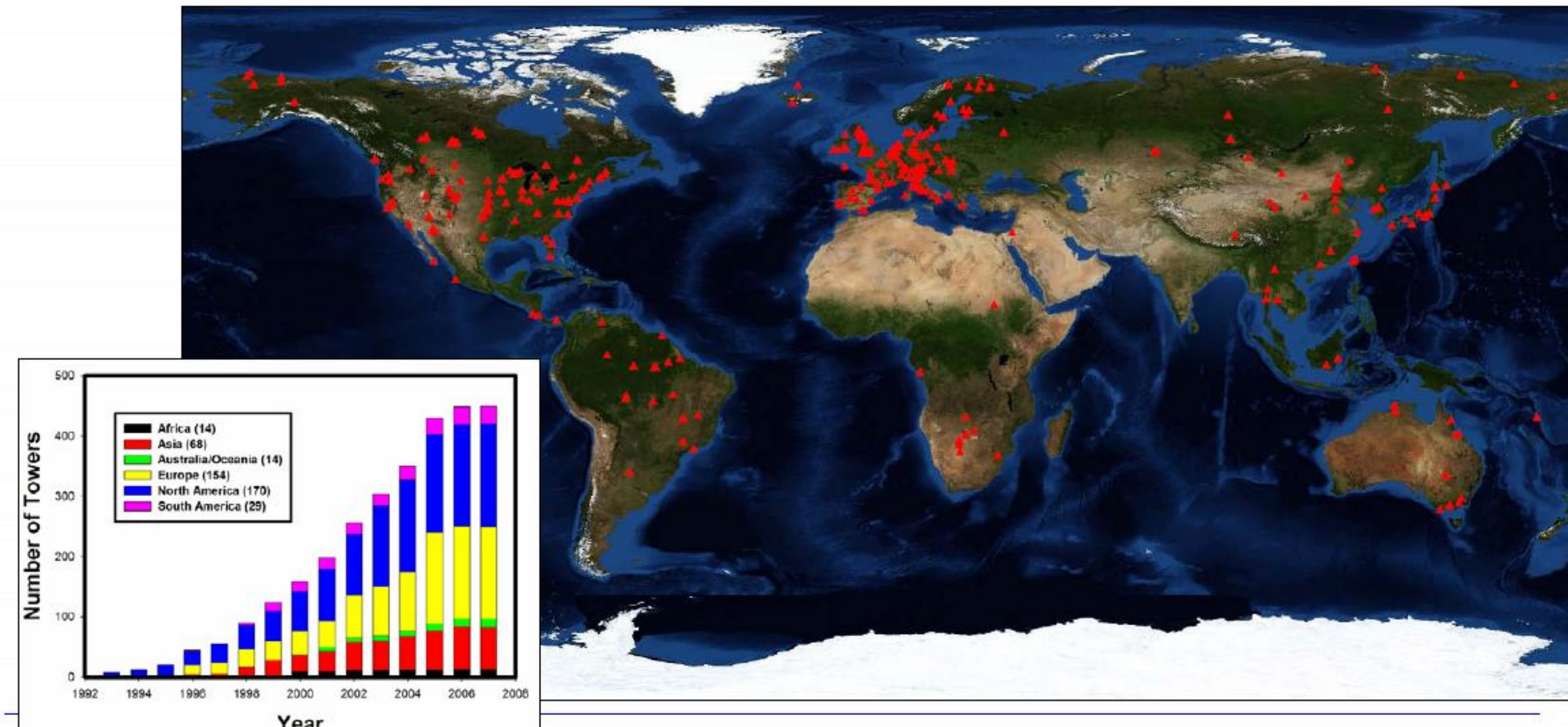
$$ET = f(PET, LAI, PPT, SM)$$



The NOAA Soil Moisture Accounting Model

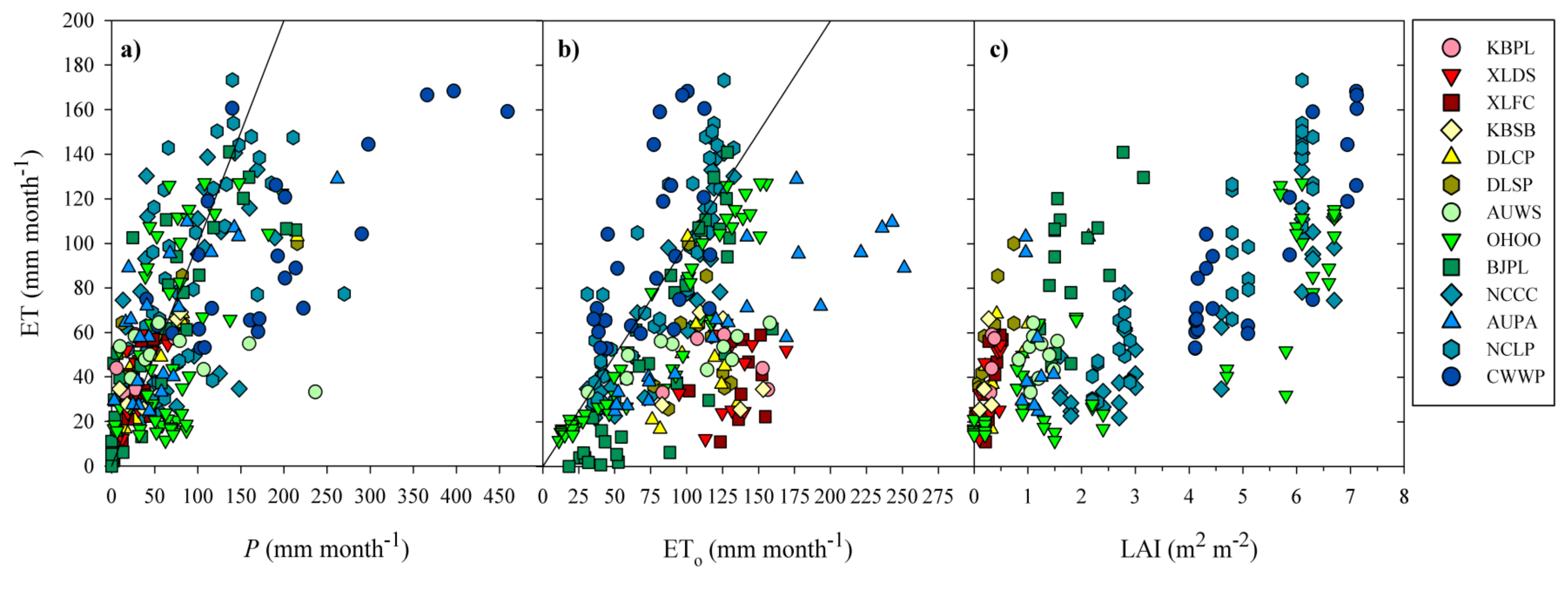
Distribution of Flux Towers Worldwide

More than 550 towers from >10 regional networks and 46 countries worldwide



Eddy flux and Sapflow Data

(Sun et al., 2010 Ecohydrology)

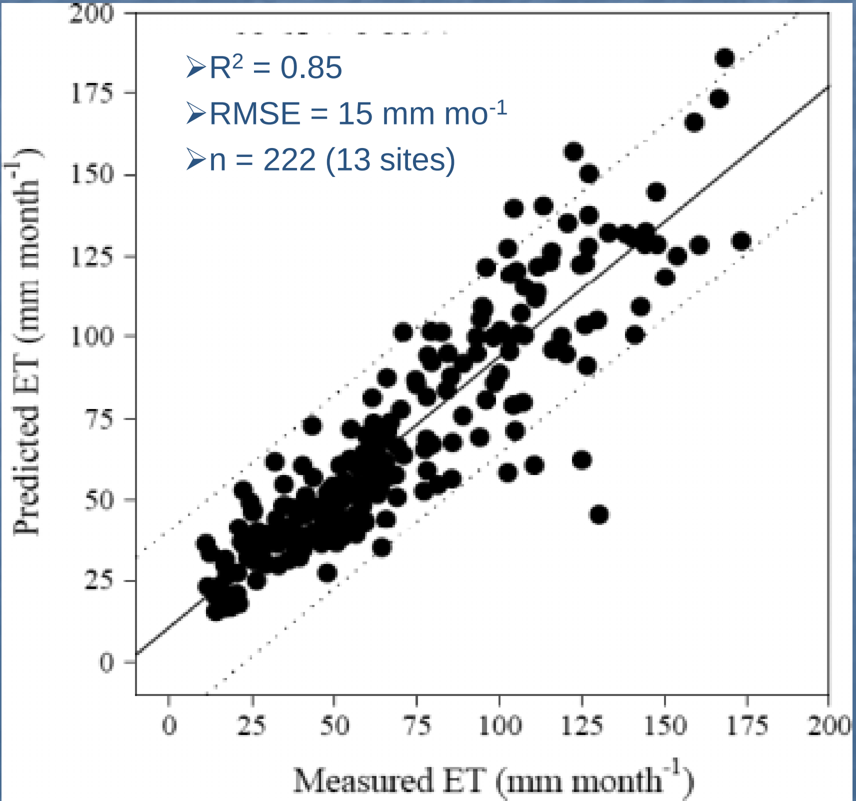


ECOHYDROLOGY
Ecohydrol. (2010)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/eco.194

A general predictive model for estimating monthly ecosystem evapotranspiration

Ge Sun,[1]* Karrin Alstad,[2] Jiquan Chen,[2] Shiping Chen,[3] Chelcy R. Ford,[4] Guanghui Lin,[3] Chenfeng Liu,[5] Nan Lu,[2] Steven G. McNulty,[1] Haixia Miao,[3] Asko Noormets,[6] James M. Vose,[4] Burkhard Wilske,[2] Melanie Zeppel,[7] Yan Zhang[5] and Zhiqiang Zhang[5]

ET= 11.94 + 4.76*LAI+PET *(0.032*LAI+0.0026*P+0.15)



An General Evapotranspiration Model

ET= 9.95 + 0.21*PET*LAI*+0.153*P+0.246*PET

Where,

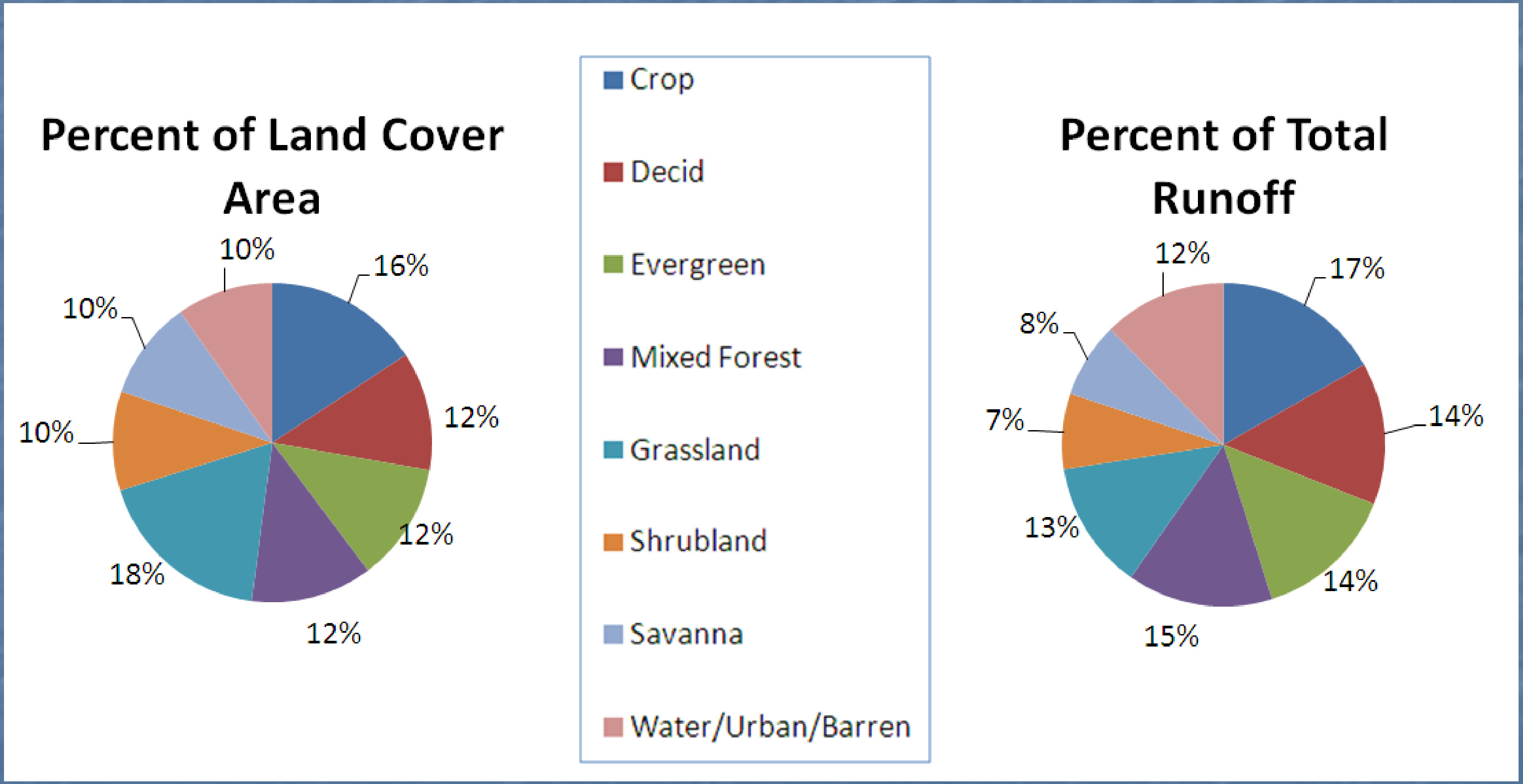
ET = Evapotranspiration (mm/month)

PET = Potential ET estimated by Hamon’s method

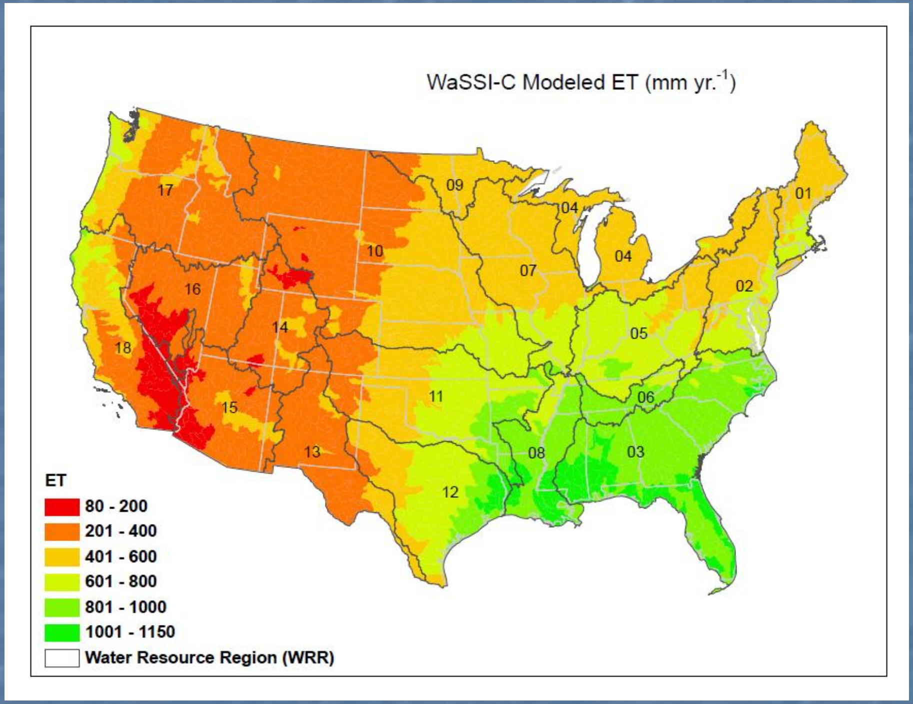
LAI = Leaf Area Index

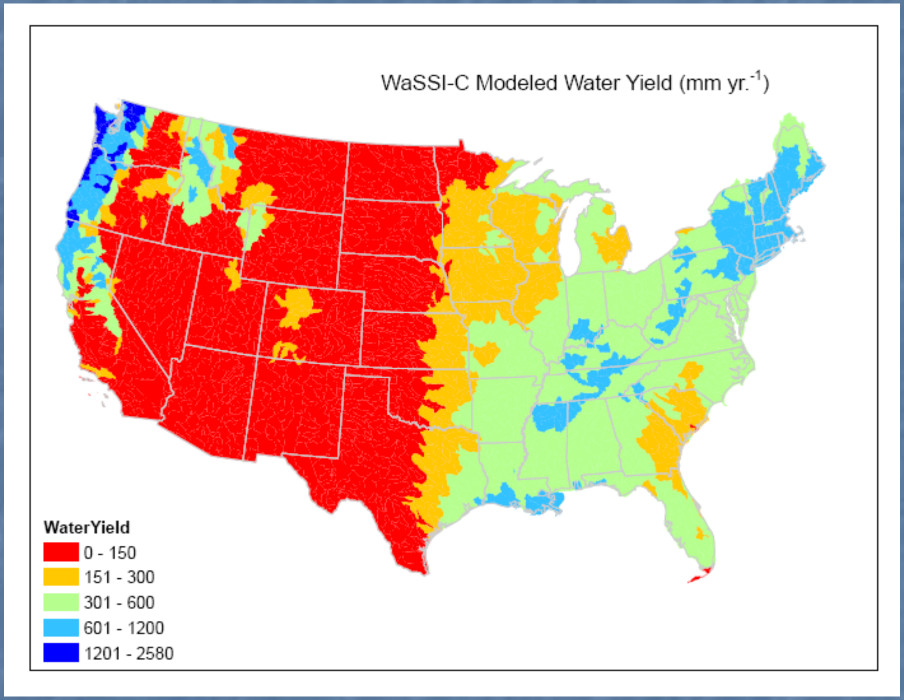
P = Precipitation (mm/month)

Model Result Example: Water Yield



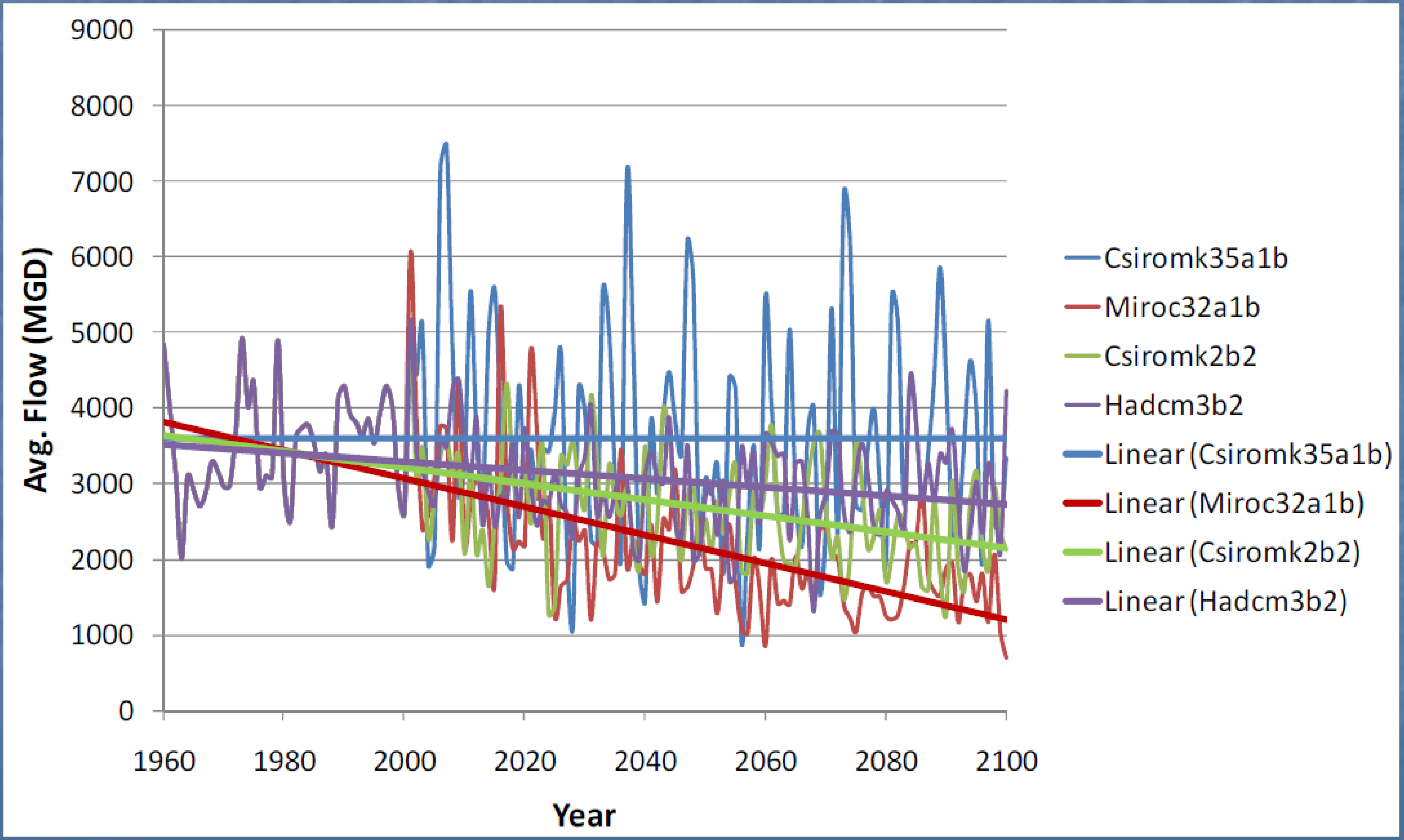
Modeled Regional Water Balance



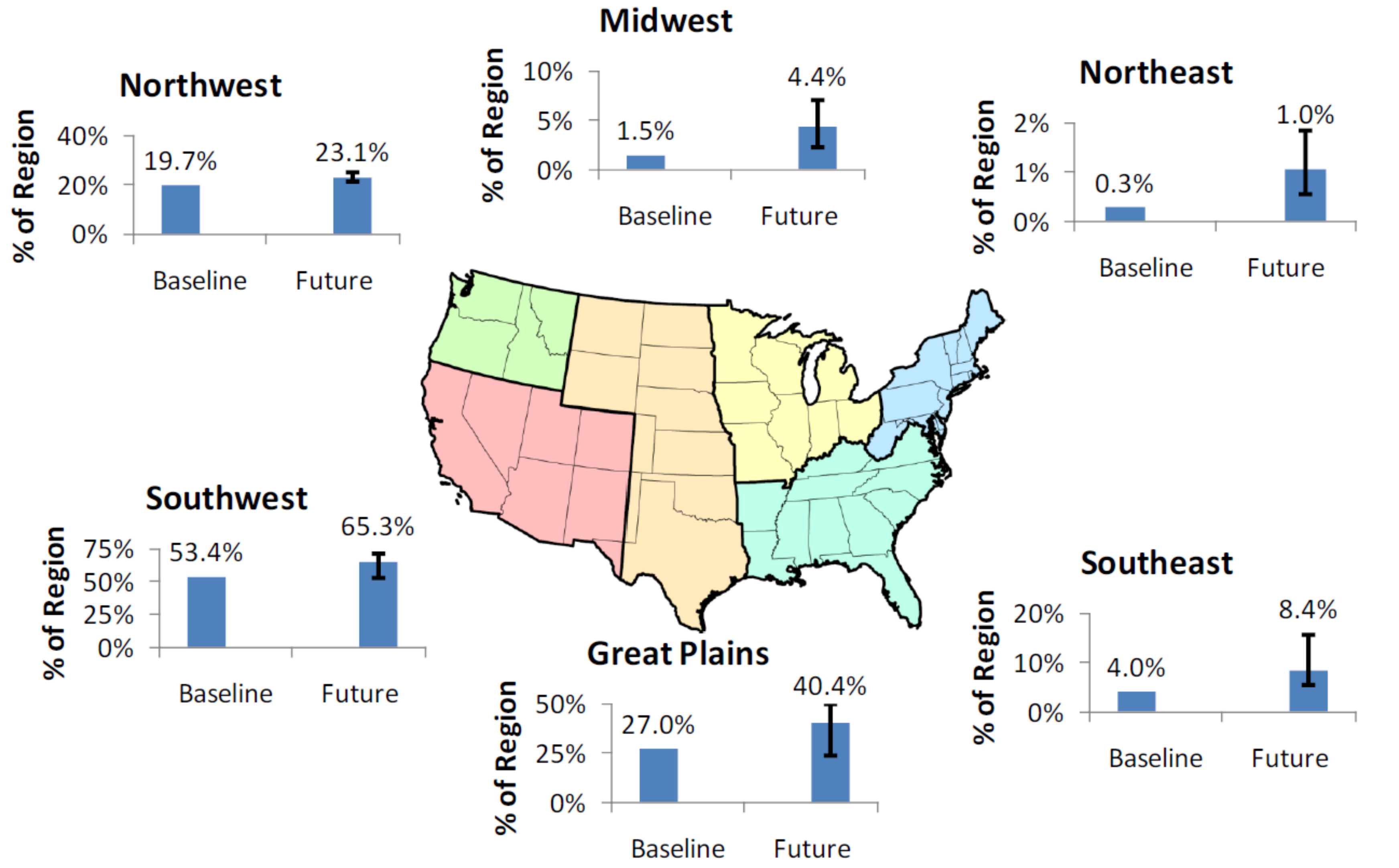


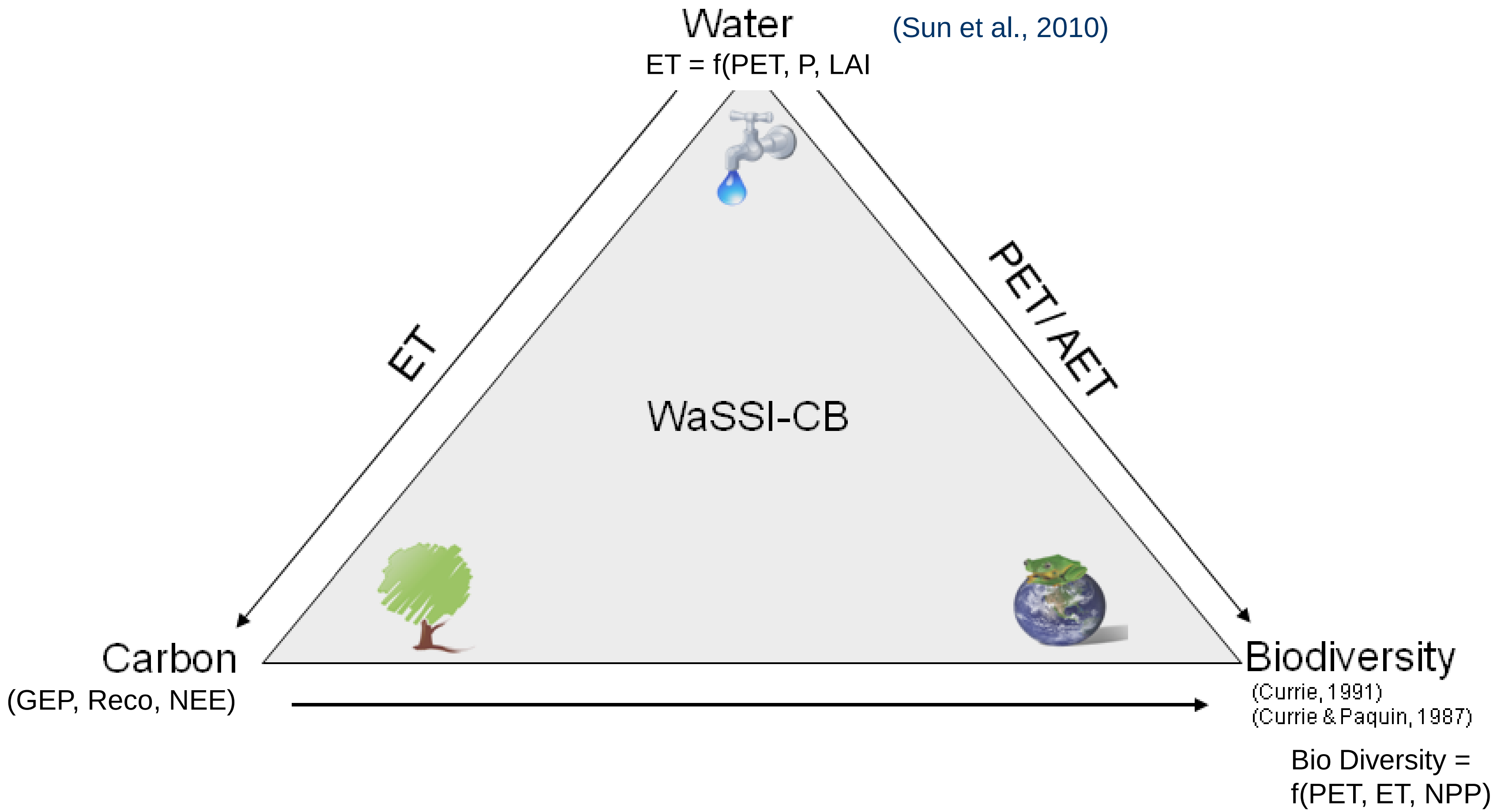
Sun et al., JGR-Biogeoscience, (2011)

Predicted the Future: Water Yield



Regional water stress (WaSSI≥0.4)

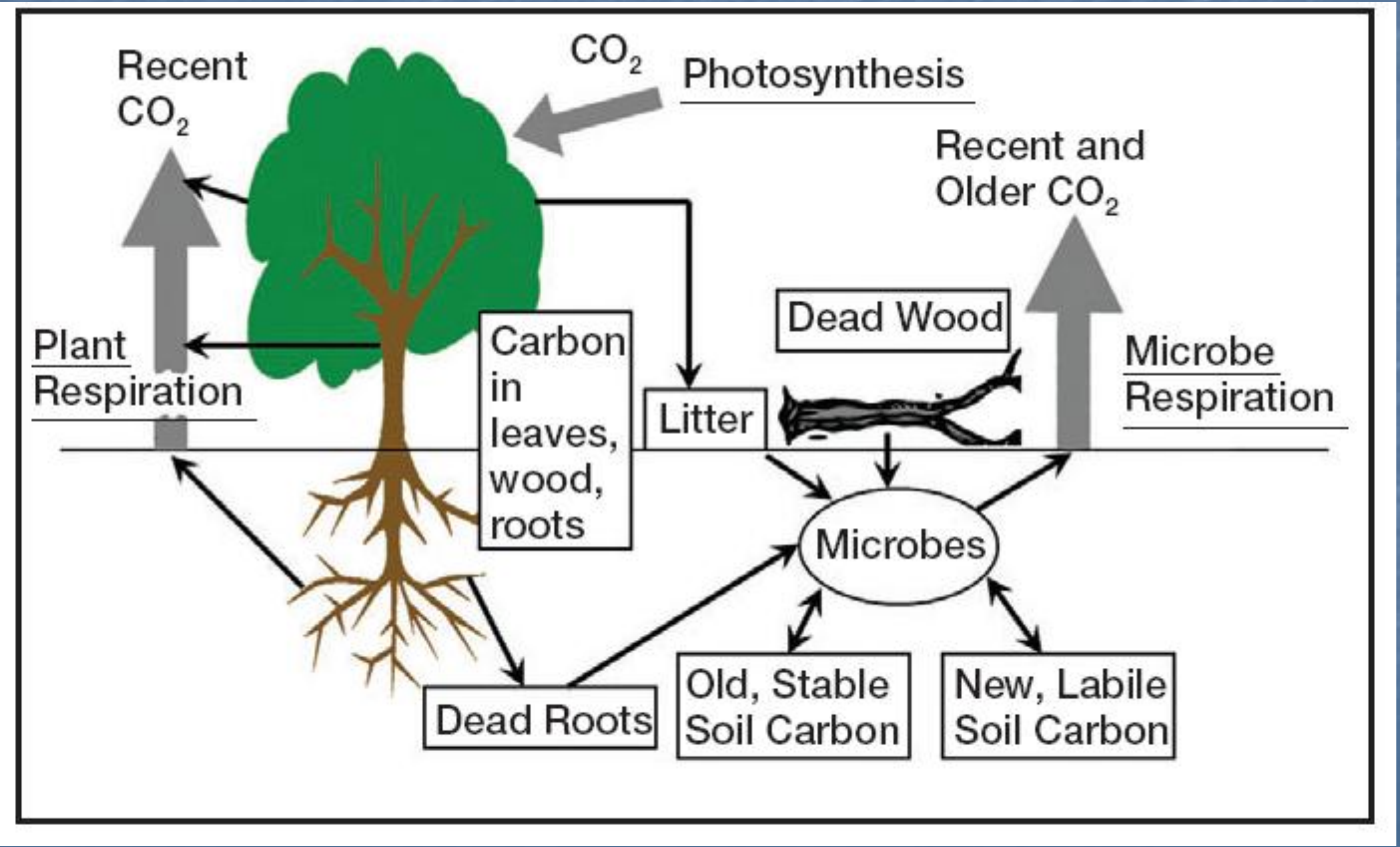




WaSSI-CB Modeling Framework

Carbon Cycle of A Forest Ecosystem

(Ryan et al., 2010)



Key Carbon Balance Terms

NEP = GEP - Re

NEE= - NEP

Where,

NEE = Net Ecosystem Exchange (gC/m2/yr.);

Negative Carbon sink ; Positive- carbon source

GEP = Gross Ecosystem Productivity (gC/m2/yr.)

Re = Ecosystem Respiration (gC/m2/yr.) = Ra+Rh;

Annual Carbon Fluxes of a pine Plantation in North Carolina, USA
(g C m^{-2} yr^{-1})

	3-yr LP					17-yr LP				
	2005	**2006**	**2007**	**2008**	**2009**	**2005**	**2006**	**2007**	**2008**	**2009**
NEE	+904	+365	+193	-97	-256	-360	-835	-725	-841	-889
GEP	1248	1640	1370	1639	2156	2480	2910	2765	2583	2724
ER	2150	2005	1565	1729	1915	2120	2075	2050	___	1833
ET	836	822	742	636	904	1039	1155	973	926	967
SR	1970	1510	1280	n/a	n/a	1330	1115	1140	n/a	n/a
SR:ER	0.92	0.75	0.82	n/a	n/a	0.63	0.54	0.56	n/a	n/a

Noormets et al. (2009) *Global Change Biology*

Law et al, 2002, Agri For Meteo.

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Agricultural and Forest Meteorology 113 (2002) 97–120

AGRICULTURAL AND FOREST METEOROLOGY

www.elsevier.com/locate/agrformet

Environmental controls over carbon dioxide and water vapor exchange of terrestrial vegetation

B.E. Law[a,*], E. Falge[b], L. Gu[c], D.D. Baldocchi[c], P. Bakwin[d], P. Berbigier[e], K. Davis[f], A.J. Dolman[g], M. Falk[h], J.D. Fuentes[i], A. Goldstein[c], A. Granier[j], A. Grelle[k], D. Hollinger[l], I.A. Janssens[m], P. Jarvis[n], N.O. Jensen[o], G. Katul[p], Y. Mahli[q], G. Matteucci[r], T. Meyers[s], R. Monson[t], W. Munger[u], W. Oechel[v], R. Olson[w], K. Pilegaard[x], K.T. Paw U[h], H. Thorgeirsson[y], R. Valentini[r], S. Verma[z], T. Vesala[a1], K. Wilson[s], S. Wofsy[u]

Law et al, 2002, Agri For Meteo.

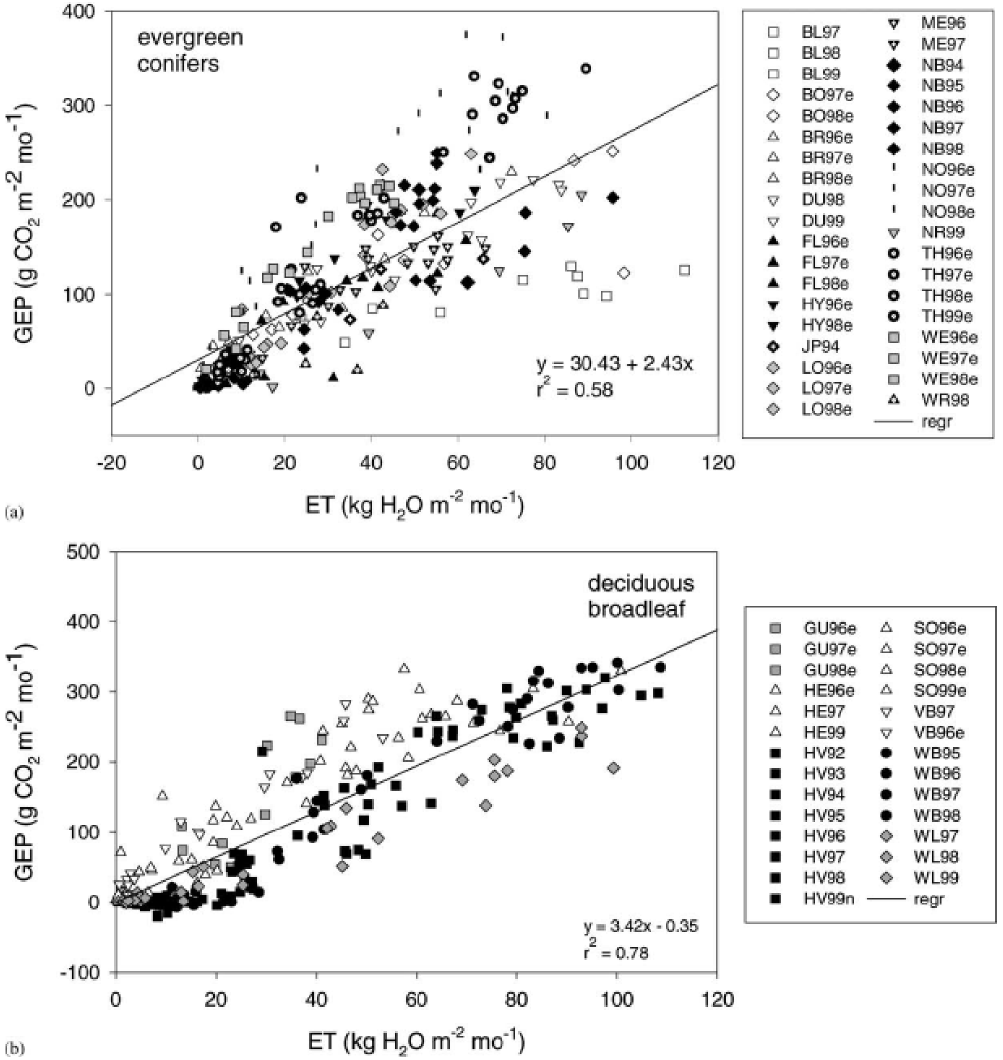


Fig. 6. Monthly GEP increased with ET in: (a) evergreen coniferous forests, where black symbols are boreal forests; (b) deciduous broadleaf forests, where gray symbols are poplar, white symbols are beech, and black symbols are oak/maple; (c) grasslands and croplands. (d) The correlation was weaker for tundra vegetation. (e) Pooled data show that the slope was similar across biomes.

Law et al, 2002, Agri For Meteo.

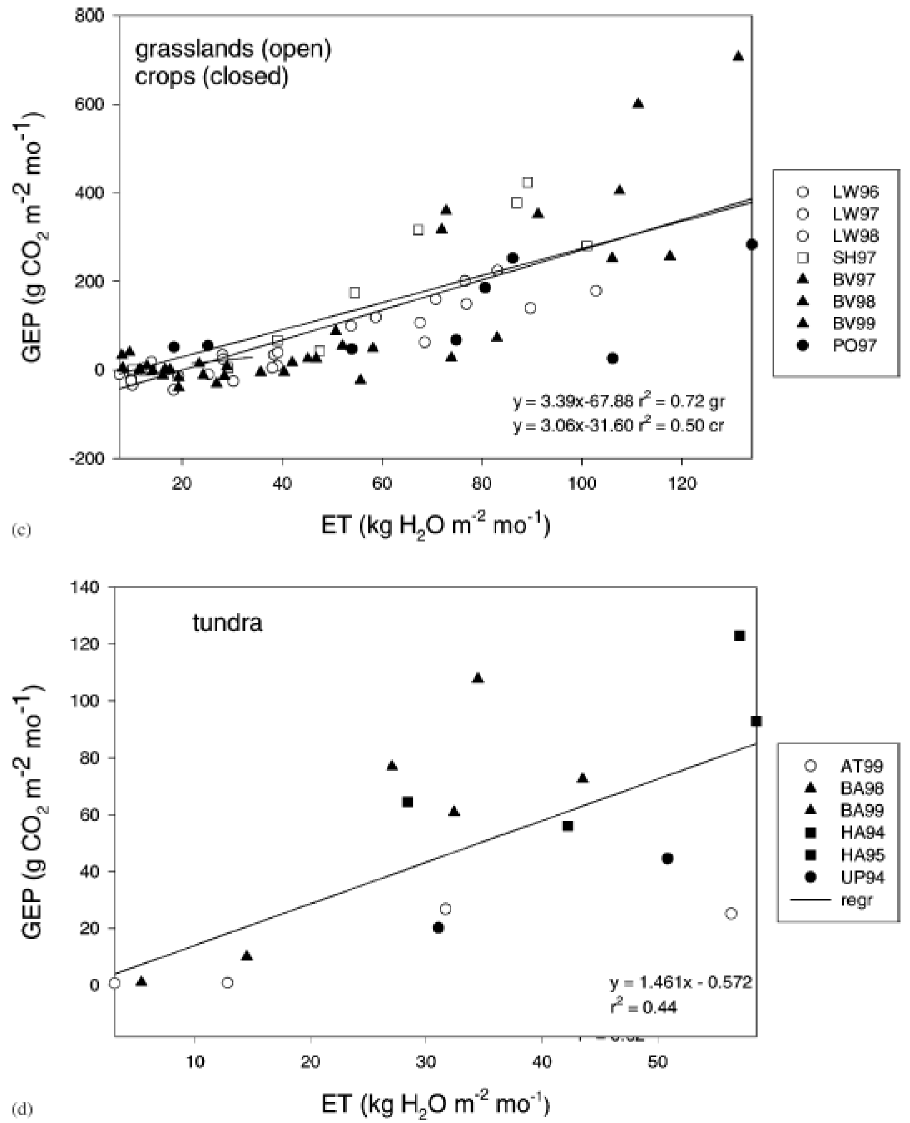
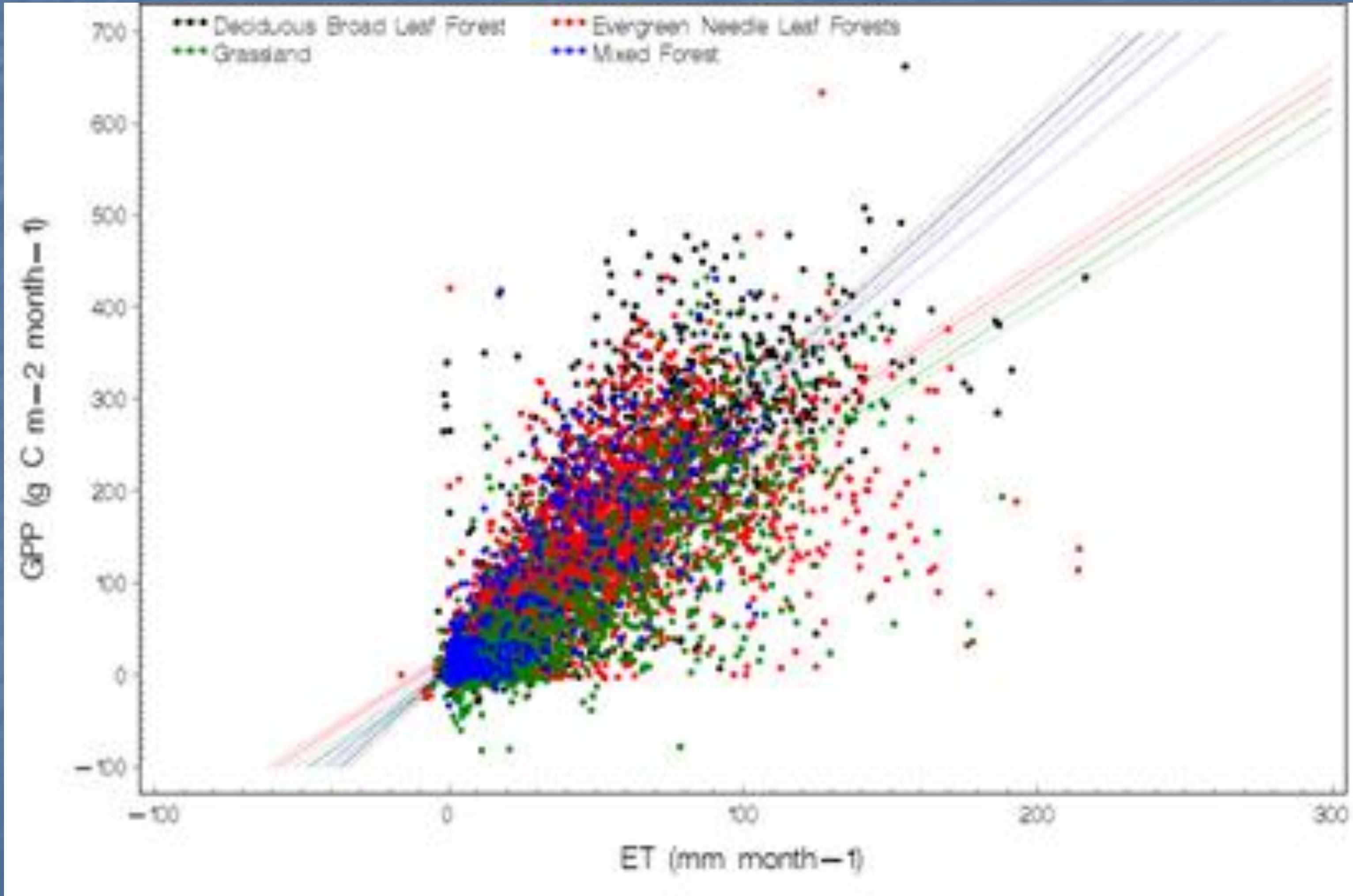


Fig. 6. (*Continued*).

Monthly GEP-ET relationship



Forest Soil Respiration

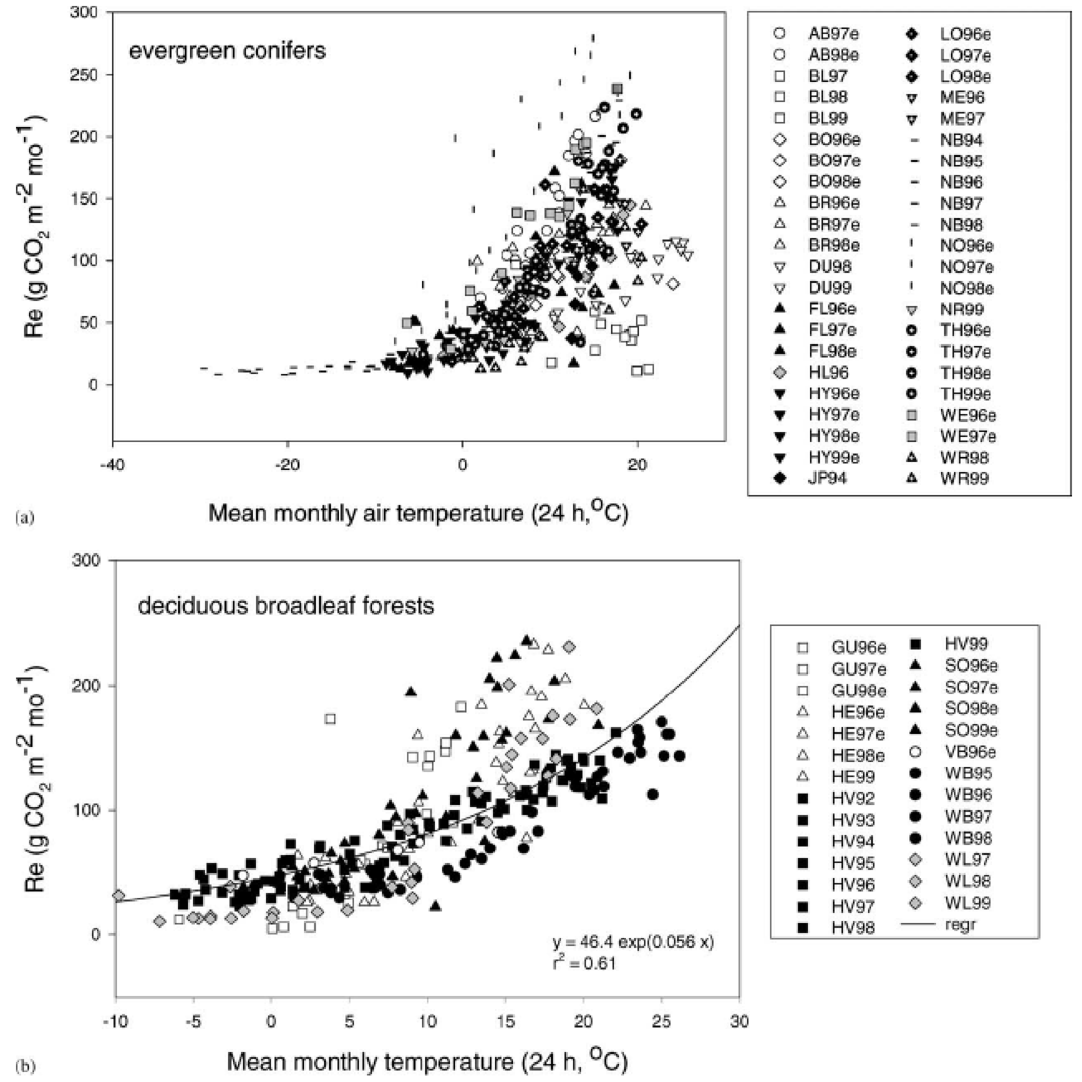


Fig. 2. Monthly cumulative ecosystem respiration increased with mean air temperature temperature at (a) evergreen coniferous forests and (b) deciduous broadleaf forests. Monthly GEP increased with temperature in evergreen coniferous forests.

Gross Ecosystem Productivity

(Sun et al, 2011, J. Geophysical Research)

Table 2. Regression model parameters for estimating monthly GEP as a function of ET, GEP = a*ET.

Land cover	Number of flux tower sites	a±SD	R^2
Croplands	29	3.13±1.69	0.78
Closed Shrublands	6	1.37±0.62	0.77
Deciduous Broad Leaf Forest	32	3.20±1.26	0.93
Evergreen Broadleaf	16	2.59±0.54	0.92
Evergreen Needle Leaf	69	2.46±0.96	0.89
Grasslands	44	2.12±1.66	0.84
Mixed Forests	12	2.74±1.05	0.89
Open Shrublands	11	1.33±0.47	0.85
Savannas	4	1.26±0.77	0.80
Wetlands	15	1.66±1.33	0.78
Wet Savannas	6	1.49±0.36	0.90

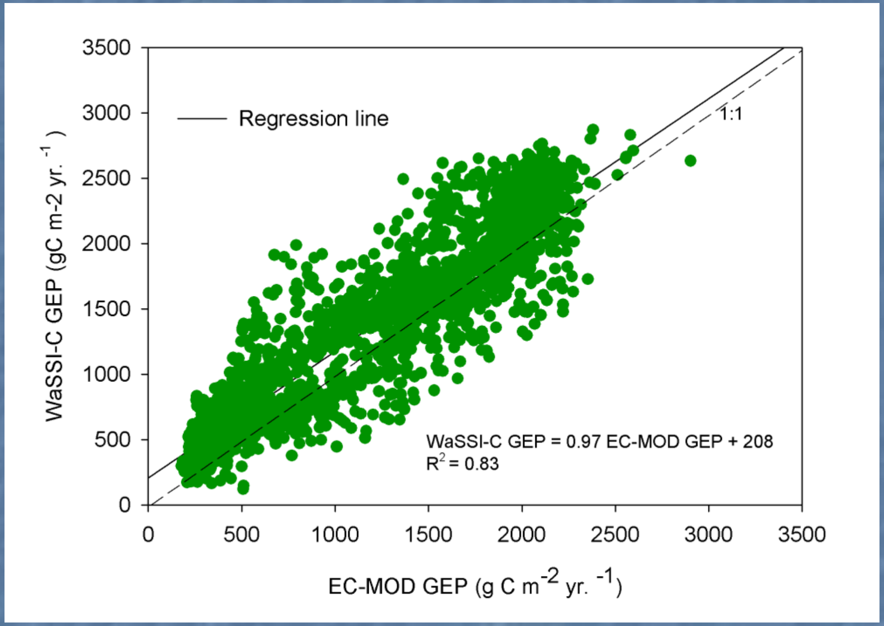
Ecosystem Respiration

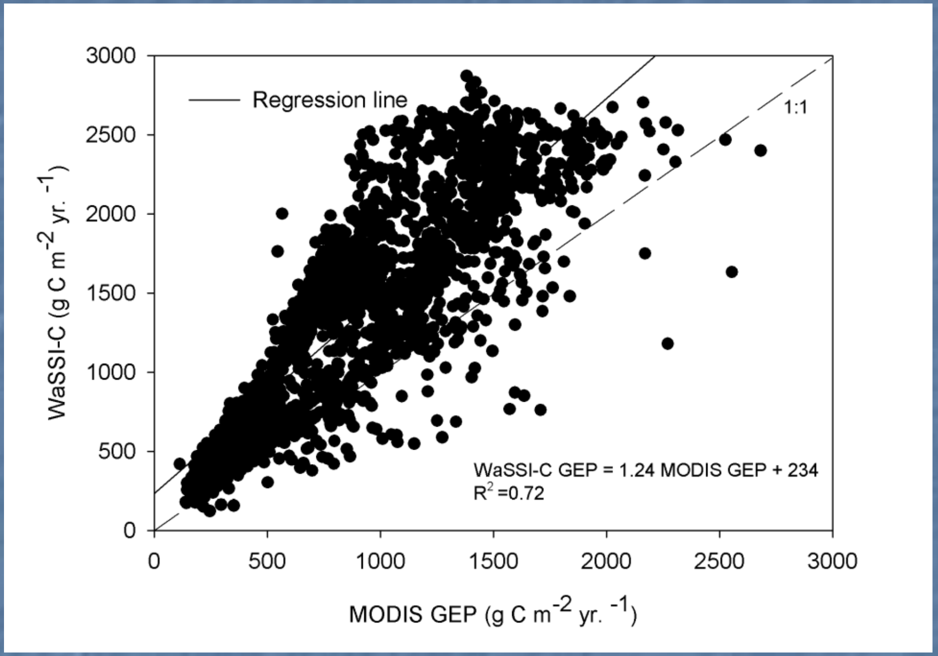
(Sun et al, 2011, J. Geophysical Research).

Table 3. Regression model parameters for estimating monthly ecosystem respiration a function of GEP, Re = m + n GEP

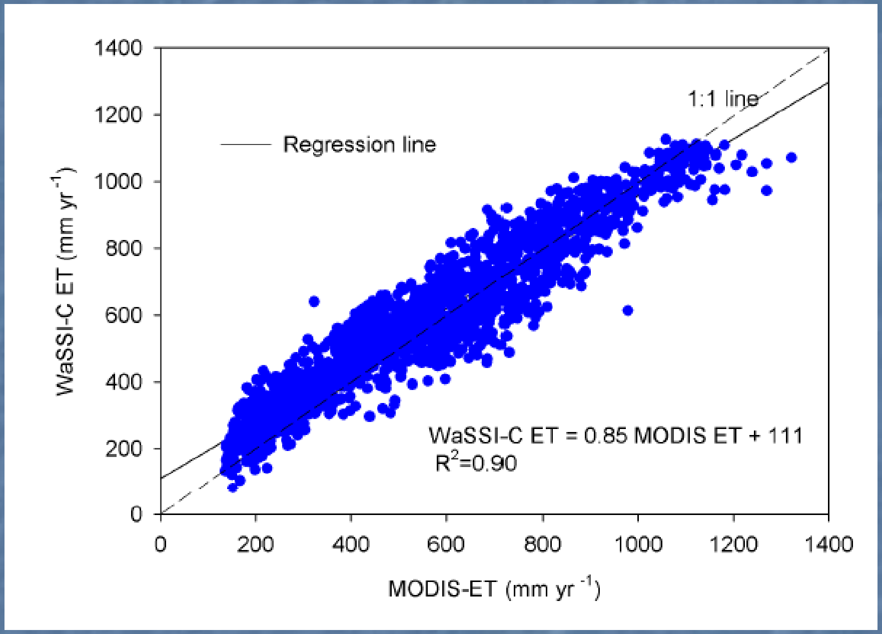
Ecosystems	Number of eddy flux sites	m±SD	n±SD	R^2
Cropland (CRO)	29	40.6±3.84	0.43±0.02	0.77
Closed Shrublands	3	11.4±15.62	0.69±0.15	0.74
Deciduous Broad Leaf Forest (DBF)	32	30.8±2.93	0.45±0.03	0.83
Evergreen Broad Leaf Forest (EBF)	11	19.6±8.74	0.61±0.06	0.63
Evergreen Needle Leaf Forest (ENF)	70	9.9±2.24	0.68±0.03	0.8
Grasslands (GRA)	44	18.9±2.31	0.64±0.02	0.82
Mixed Forests (MF)	12	24.4±4.24	0.62±0.05	0.88
Open Shrublands (OS)	8	9.7±3.03	0.56±0.08	0.81
Savannas (SAV)	3	25.2±3.23	0.53±0.07	0.65
Wetlands (WET)	15	7.8±3.04	0.56±0.03	0.8
Wet Savanna (WSA)	6	14.7±2.75	0.63±0.04	0.74

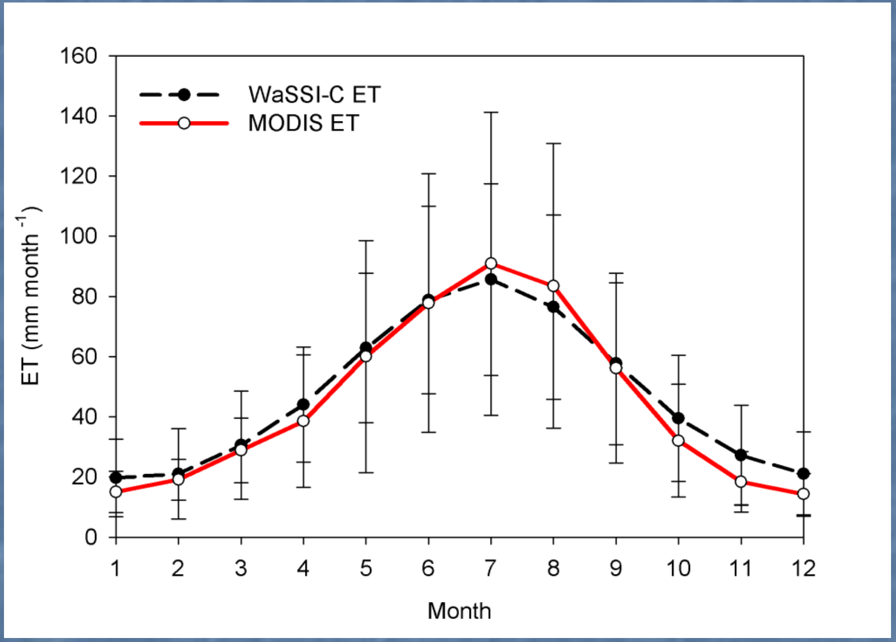
Model Validation (GEP)



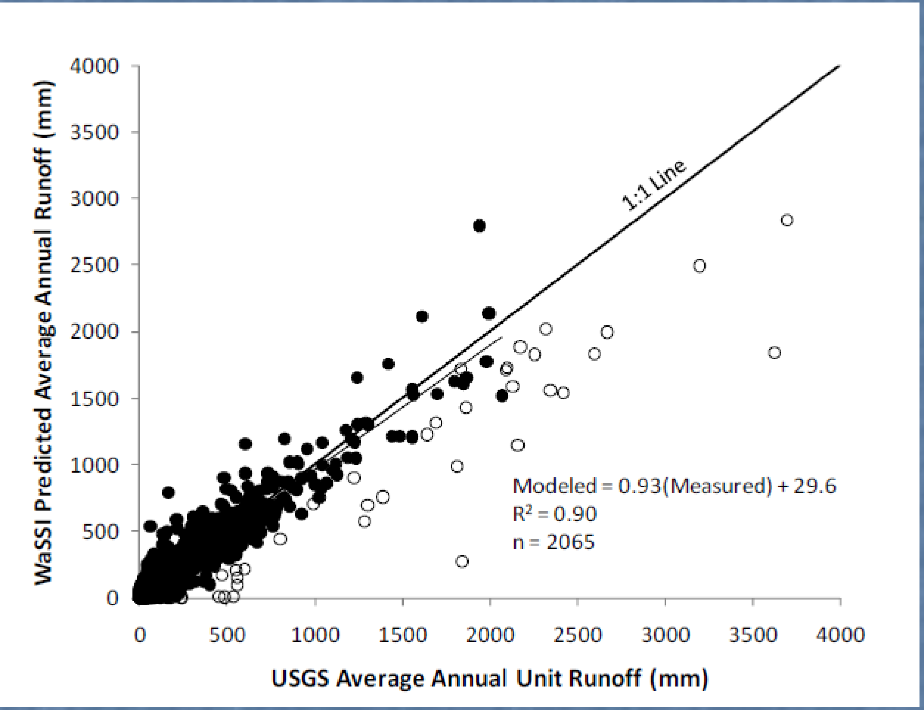


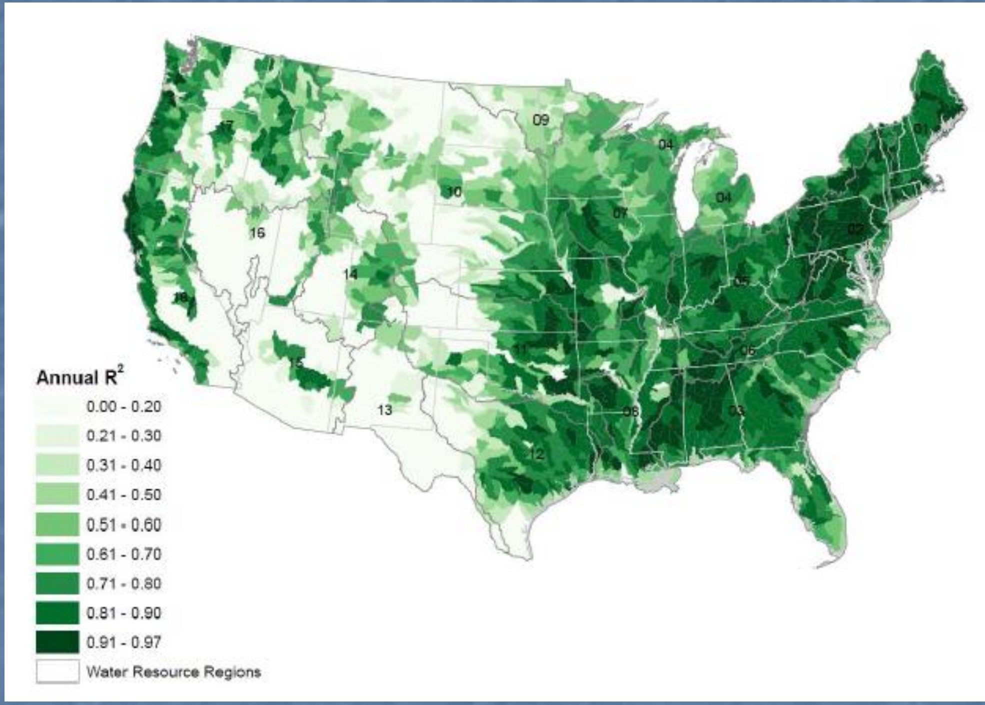
Model Validation (ET)





Model Validation (Runoff)





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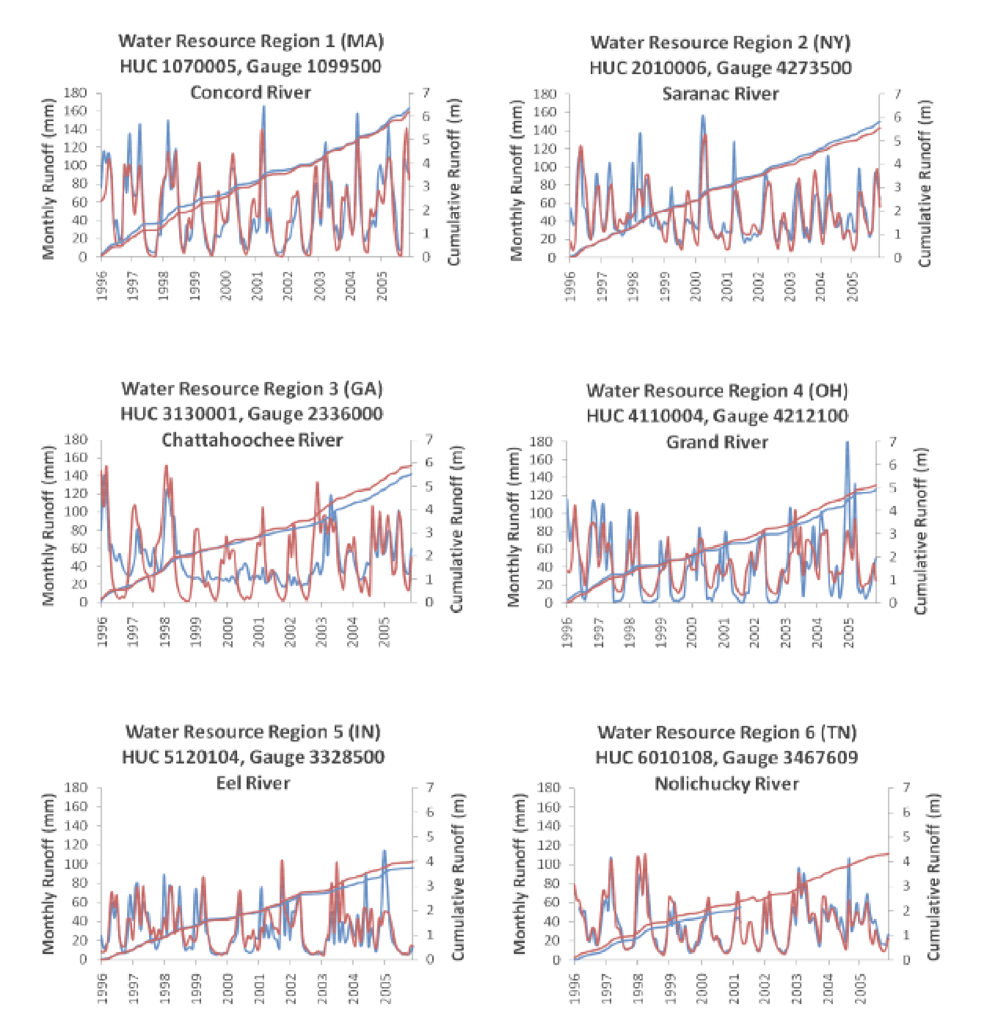

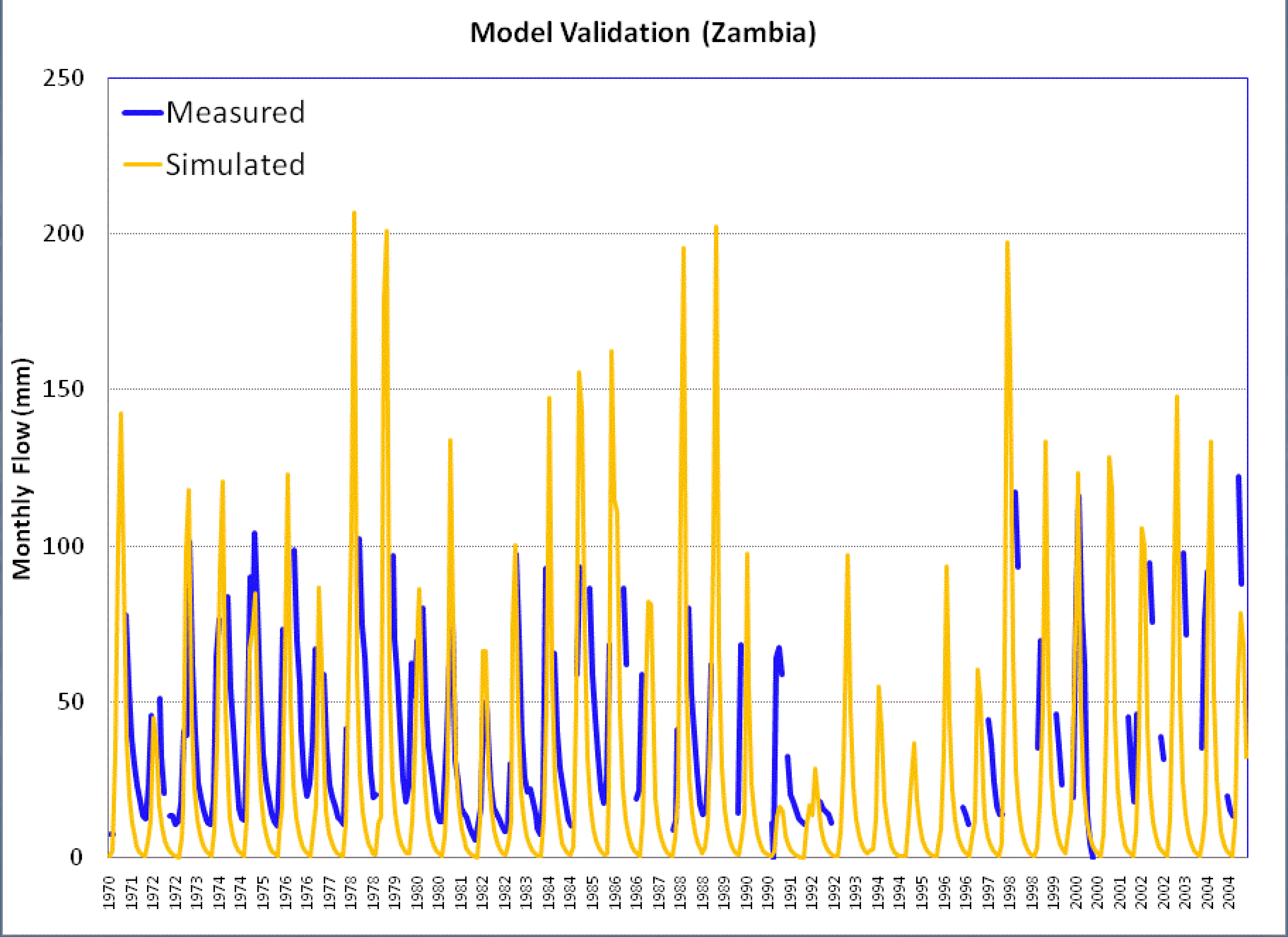

Model Validation (Zambia)
Measured
Simulated
Monthly Flow (mm)
250
200
150
100
50
0
1970
1971
1972
1972
1973
1974
1974
1975
1976
1976
1977
1978
1978
1979
1980
1980
1981
1982
1982
1983
1984
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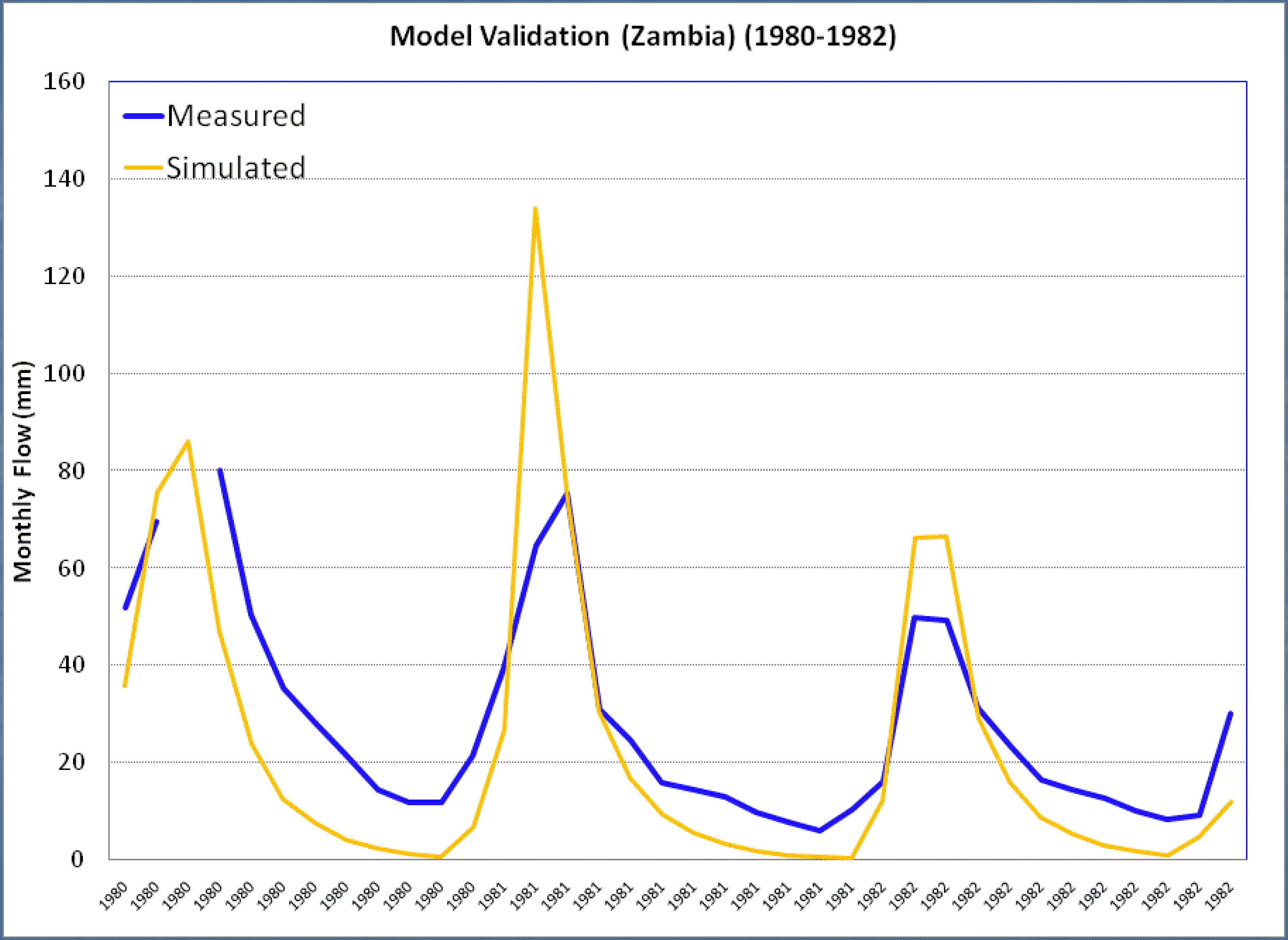
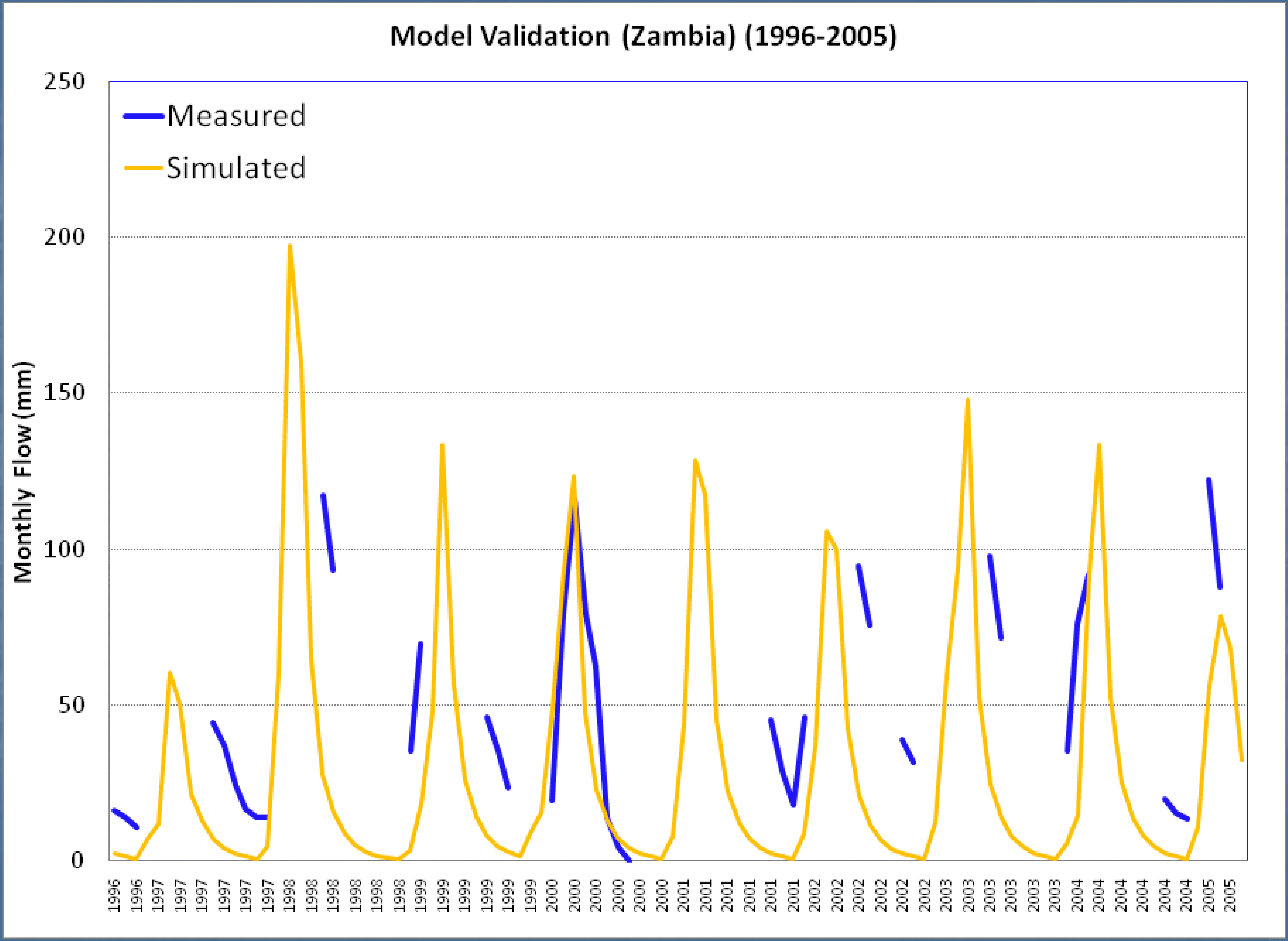
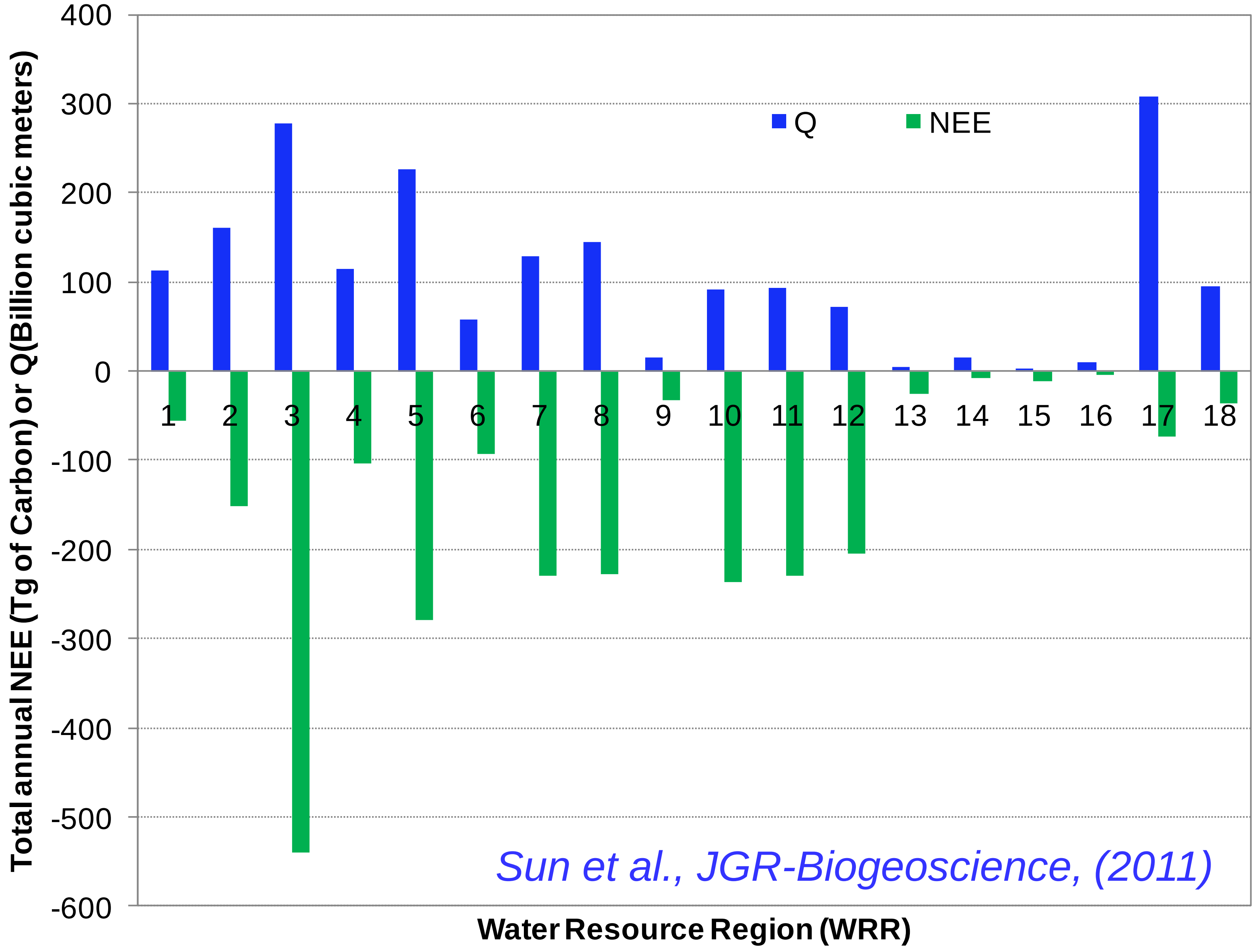
2004



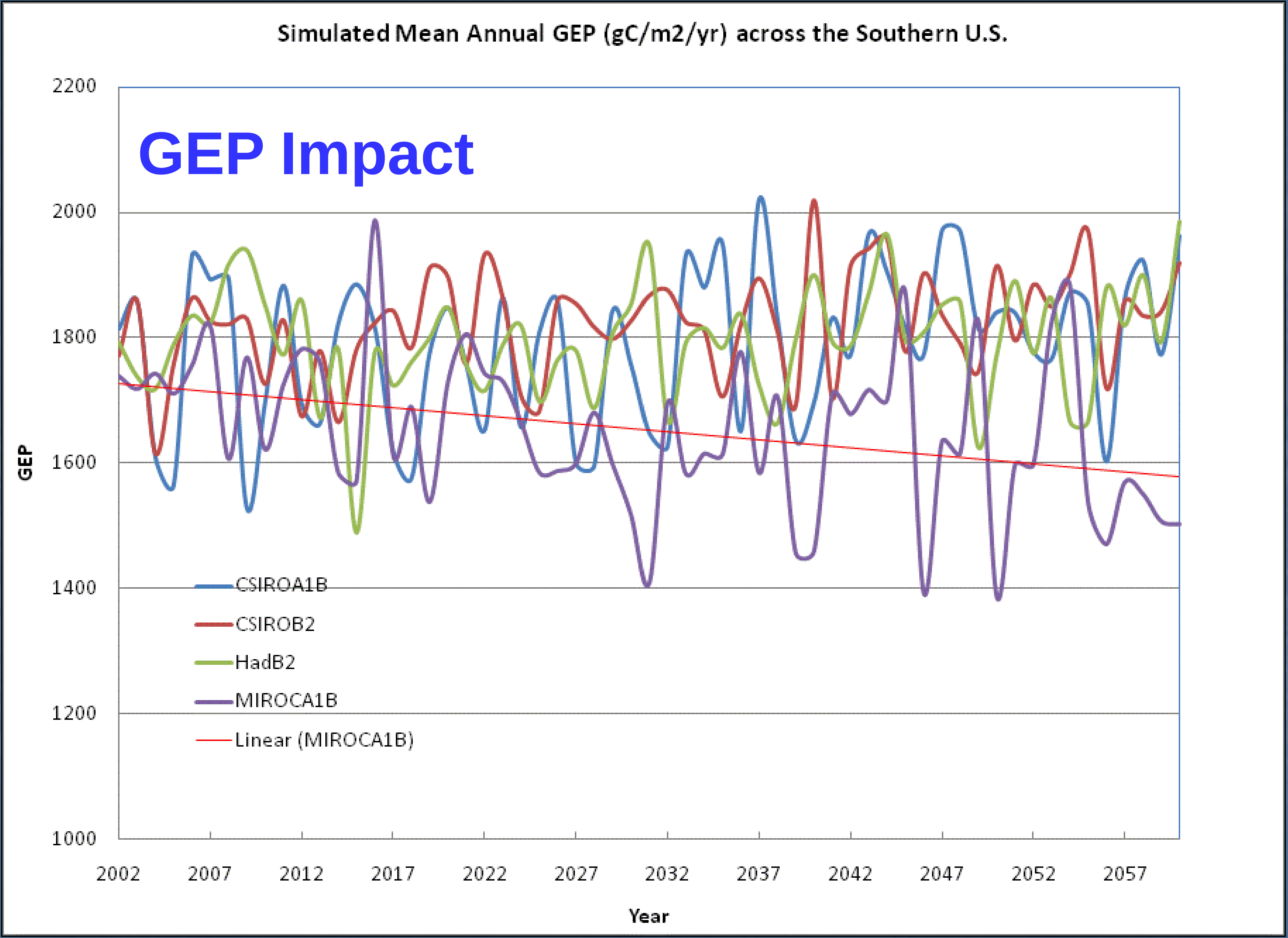
Model Validation (Zambia) (1980-1982)
Measured
Simulated
Monthly Flow (mm)
0
20
40
60
80
100
120
140
160
1980
1981
1982



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

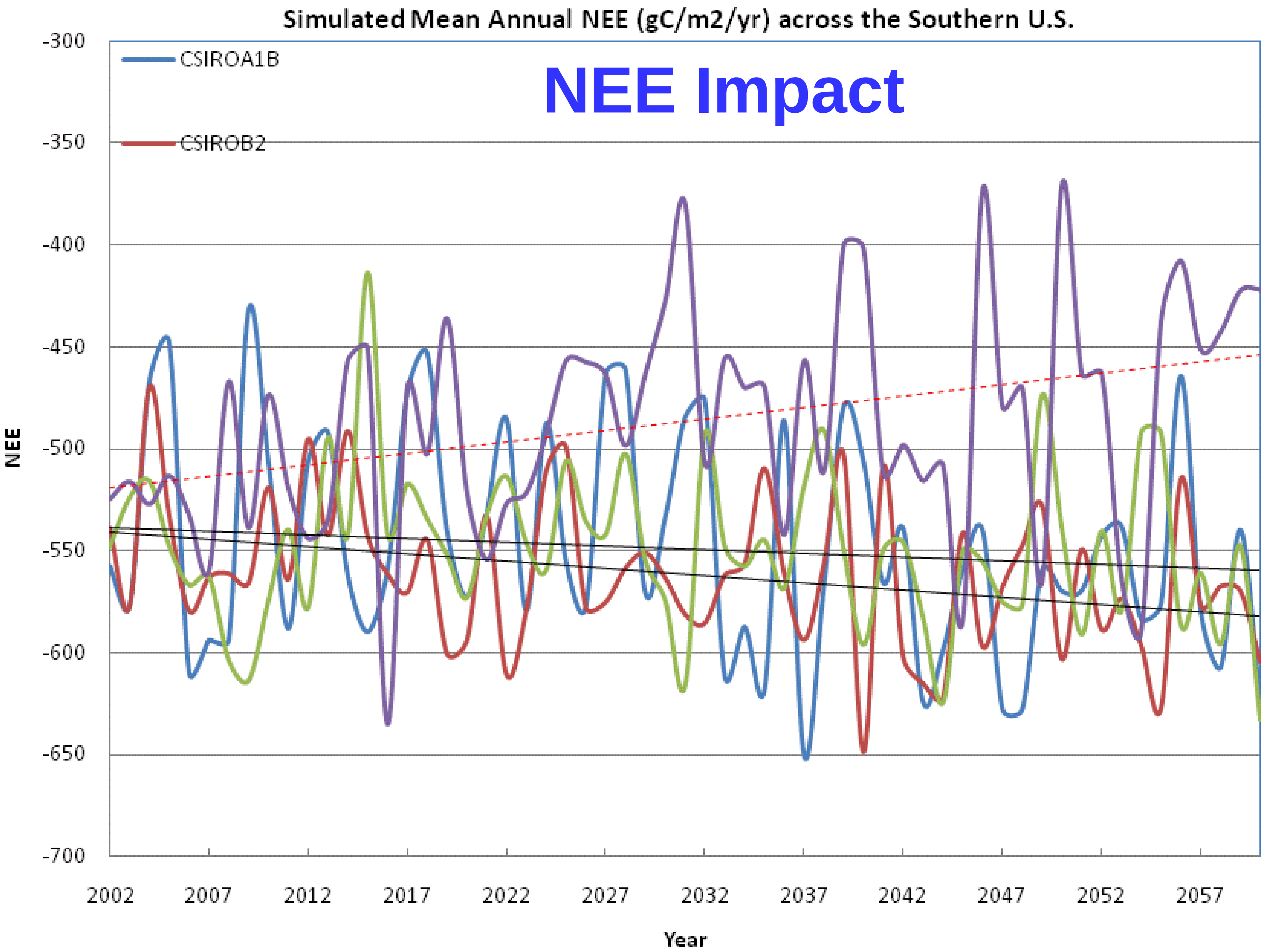


400
300
200
100
0
-100
-200
-300
-400
-500
-600
Total annual NEE (Tg of Carbon) or Q(Billion cubic meters)
Q
NEE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Sun et al., JGR-Biogeoscience, (2011)
Water Resource Region (WRR)

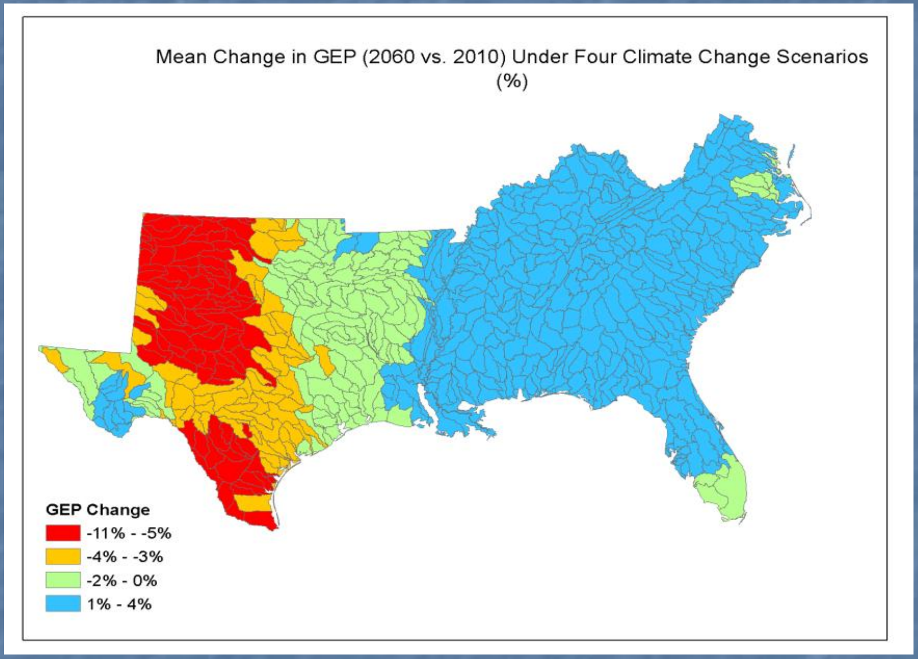


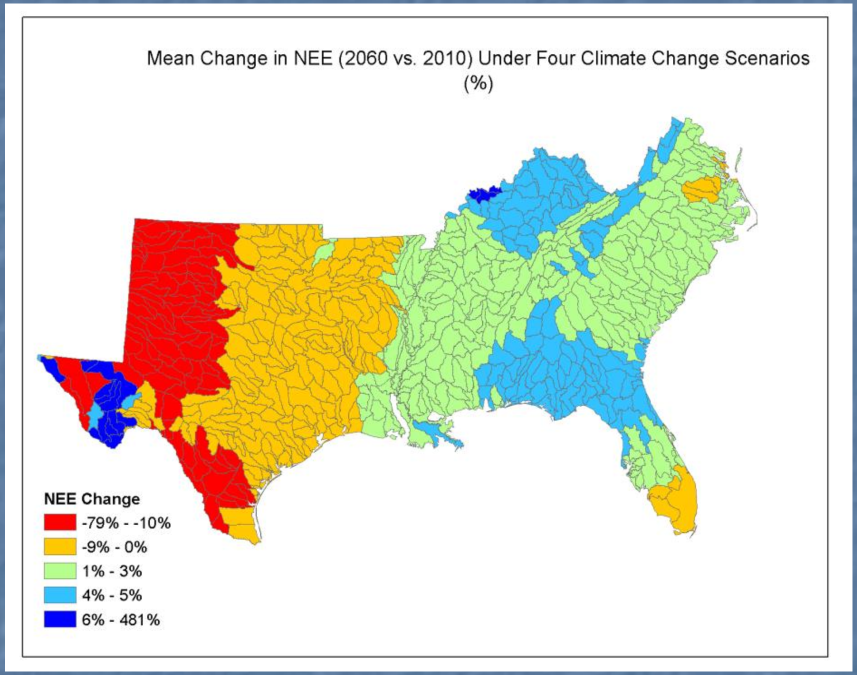
Simulated Mean Annual GEP (gC/m2/yr) across the Southern U.S.
GEP Impact
2200
2000
1800
1600
1400
1200
1000
GEP
CSIROA1B
CSIROB2
HadB2
MIROCA1B
Linear (MIROCA1B)
2002
2007
2012
2017
2022
2027
2032
2037
2042
2047
2052
2057
Year

NEE Impact

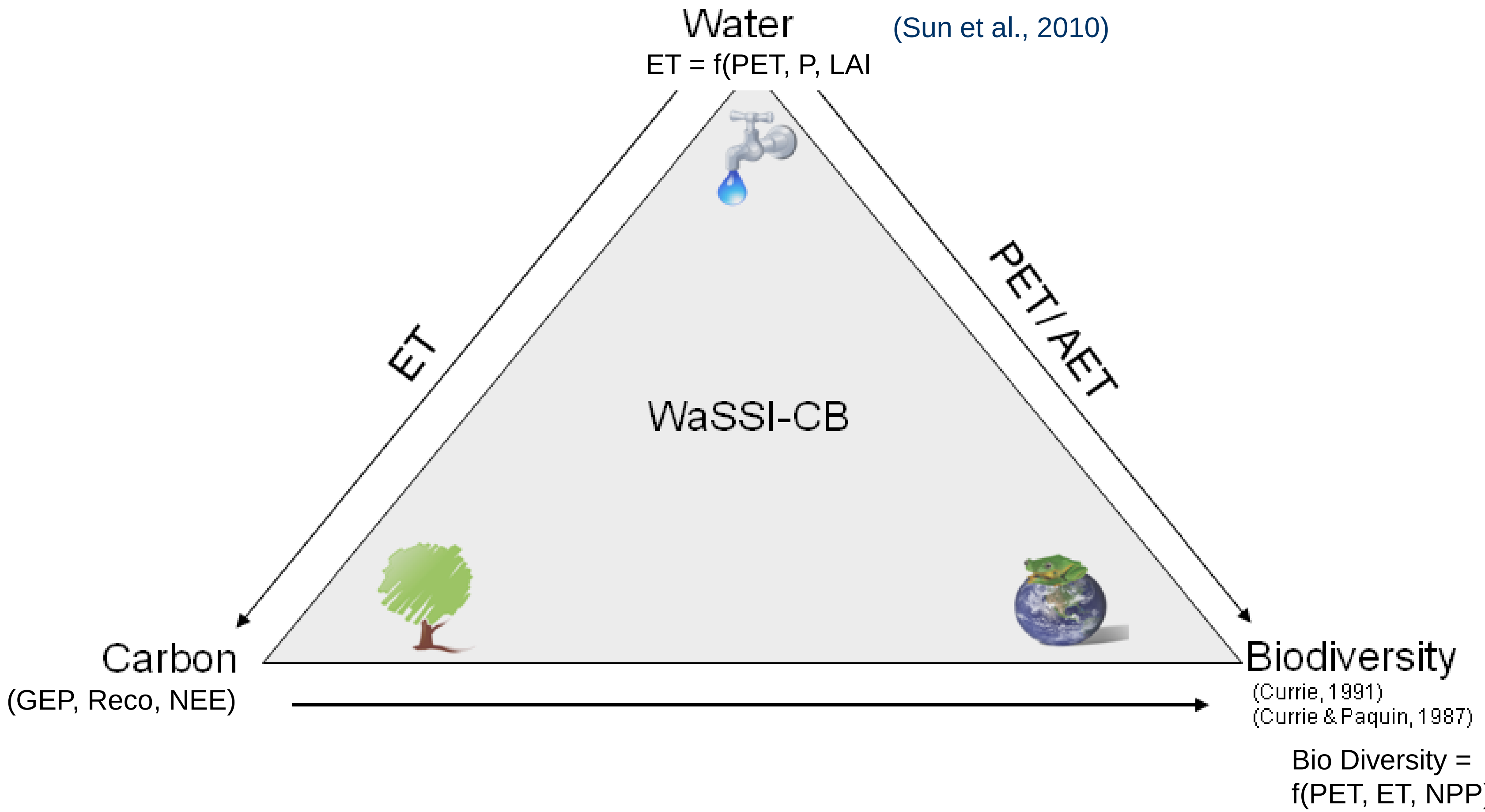

Simulated Mean Annual NEE (gC/m2/yr) across the Southern U.S.
CSIROA1B
CSIROB2
NEE
-300
-350
-400
-450
-500
-550
-600
-650
-700
2002
2007
2012
2017
2022
2027
2032
2037
2042
2047
2052
2057
Year

Modeled Climate Change Impact on Carbon in the South





Model Development: Biodiversity



WaSSI-CB Modeling Framework

Biodiversity Modeling
(Currie, 1991; Currie and Paquin, 1987)

Group	Domain	Model	r^2
Birds	PET < 525 mm yr^{-1}	1.40 + .00159 PET	
	PET ≥ 525 mm yr^{-1}	2.26 − .0000256 PET	.81
Mammals	All observations	1.12[1.0 − exp(−0.00348 PET)] + .653	.80
Amphibians	PET ≤ 200 mm yr^{-1}	0	
	PET > 200 mm yr^{-1}	3.07[1.0 − exp(−0.00315 PET)]	.84
Reptiles	PET < 400 mm yr^{-1}	0	
	PET ≥ 400 mm yr^{-1}	5.21[1.0 − exp(−0.00249 PET)] − 3.347	.93
Vertebrates	All observations	1.49[1.0 − exp(−0.00186 PET)] + .746	.92

Tree Species Richness = 185.8/[1.0 + exp(3.09 - 0.00432 ET)] ;

$r^2 = 0.76$

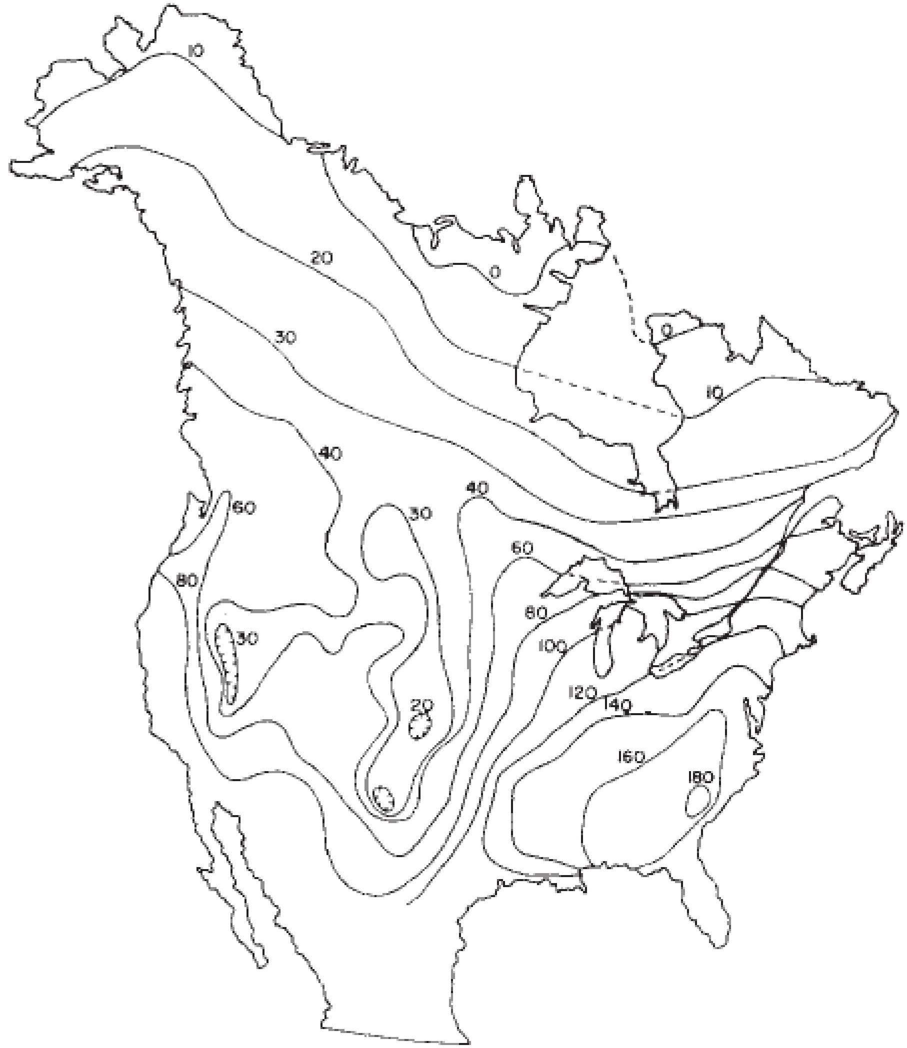
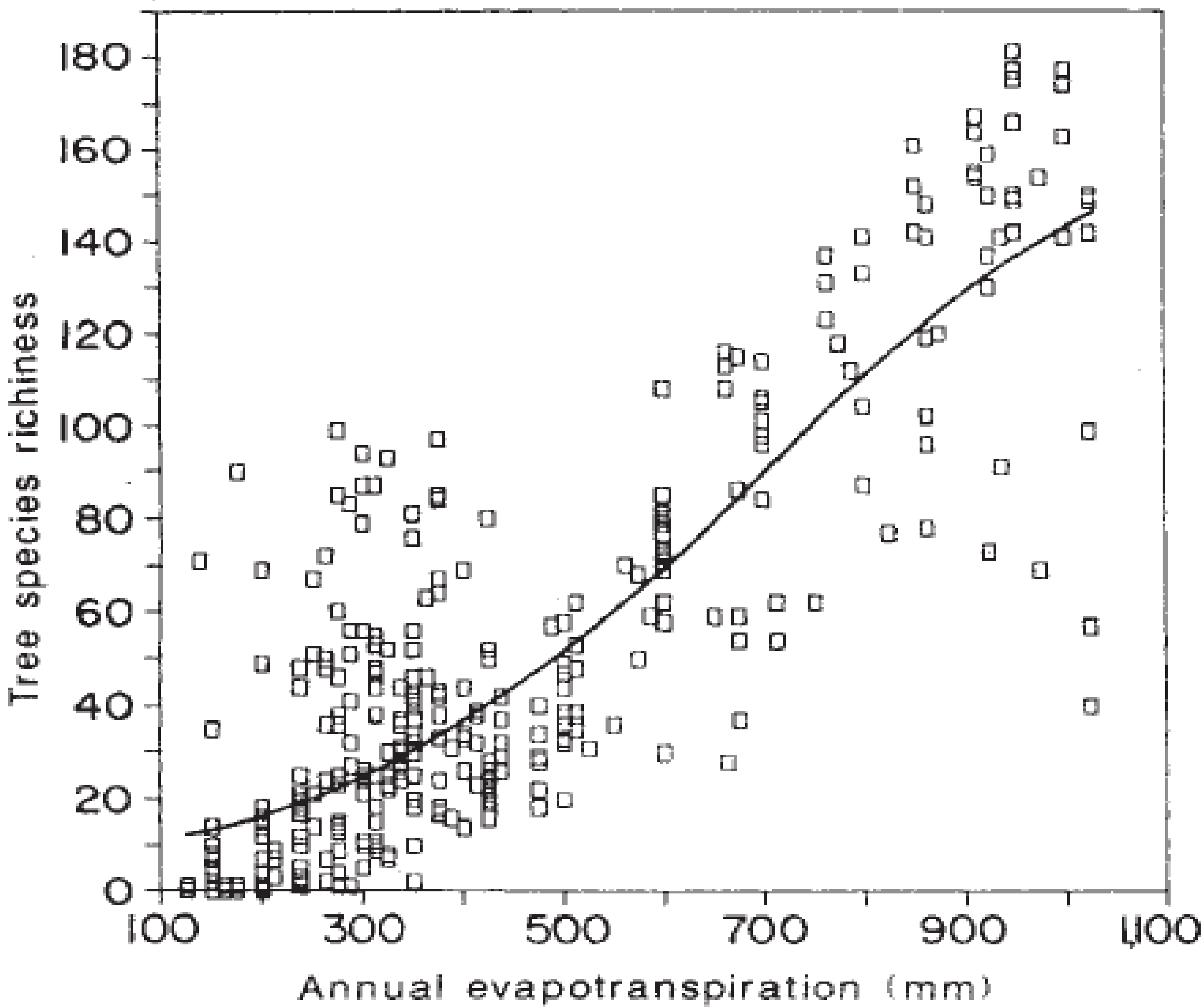


Fig. 1 Tree species richness in Canada and the United States. Contours connect points with the same approximate number of species per quadrat.

Large-scale biogeographical patterns of species richness of trees

David J. Currie & Viviane Paquin

Biology Department, University of Ottawa, 30 Somerset East, Ottawa, Ontario K1N 6N5, Canada



Large-scale biogeographical patterns of species richness of trees

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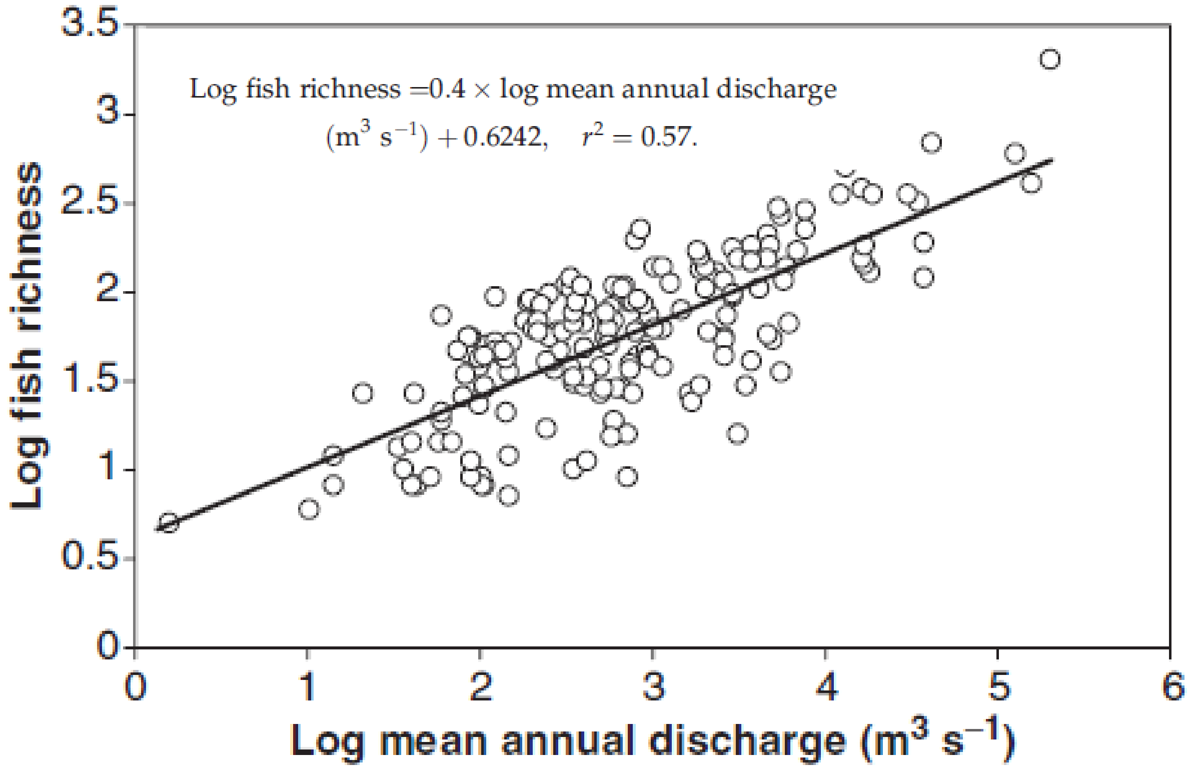
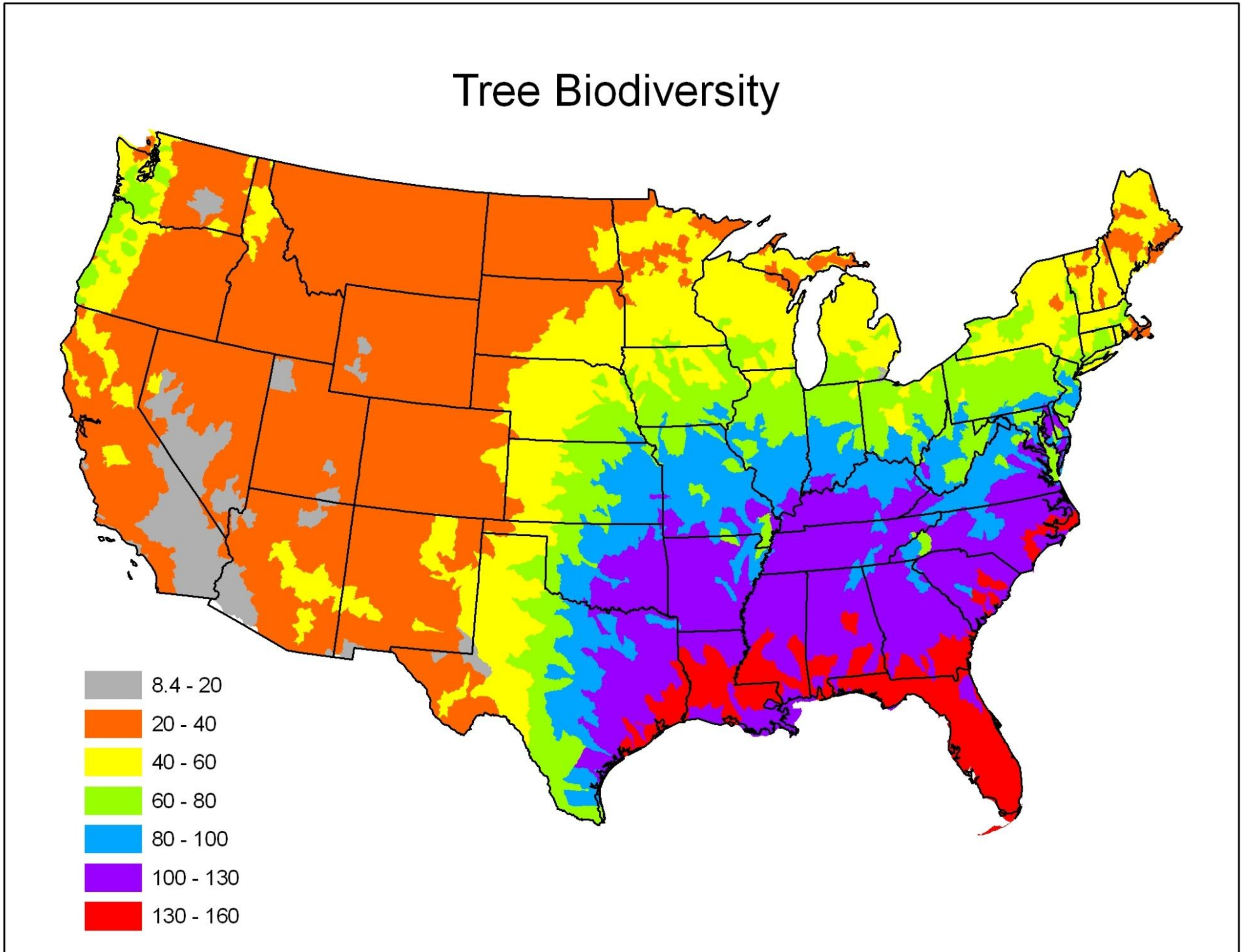


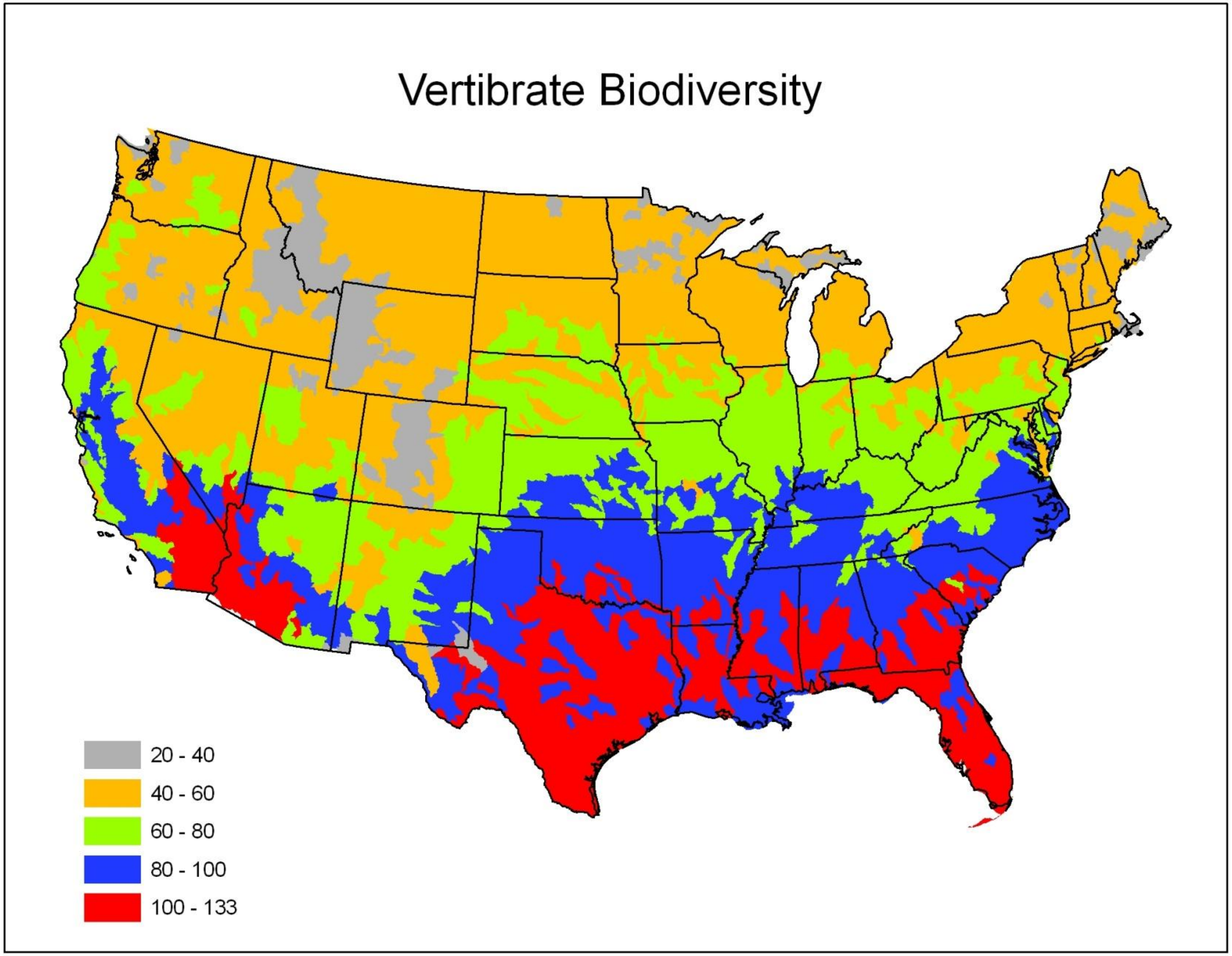
Fig. 1 Fish species–discharge curve used to build scenarios of fish loss. The regression was modeled with rivers found between 42°N and 42°S, where reduced discharge is predicted to occur.

Global Change Biology (2005) 11, 1557–1564, doi: 10.1111/j.1365-2486.2005.01008.x

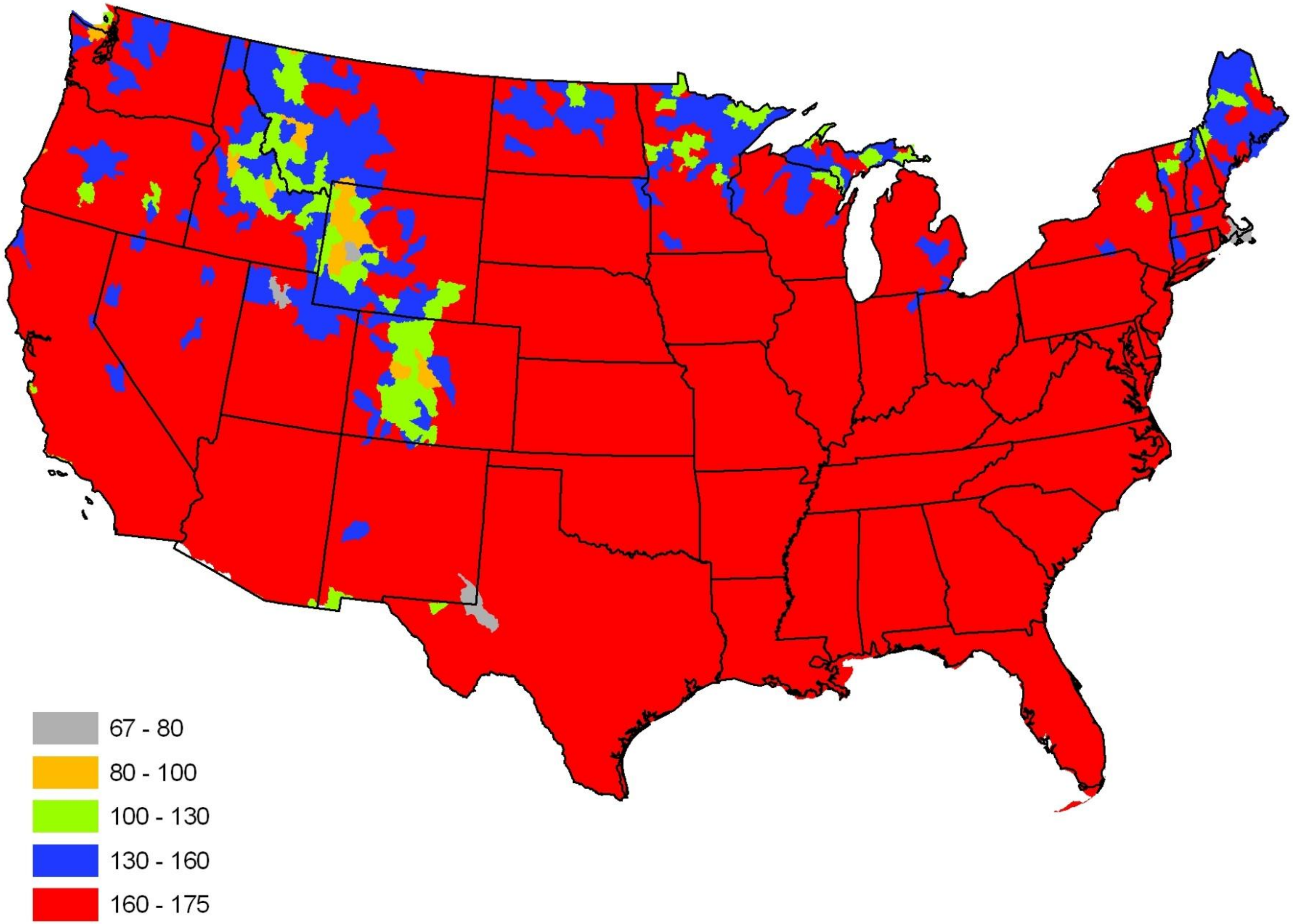
Scenarios of freshwater fish extinctions from climate change and water withdrawal

MARGUERITE A. XENOPOULOS*, DAVID M. LODGE*, JOSEPH ALCAMO†, MICHAEL MÄRKER‡, KERSTIN SCHULZE† and DETLEF P. VAN VUUREN§


Tree Biodiversity
8.4 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 130
130 - 160


Vertibrate Biodiversity
20 - 40
40 - 60
60 - 80
80 - 100
100 - 133

Bird Biodiversity



Preparing Inputs Data for Model Applications in Rwanda, Tanzania, and Zambia

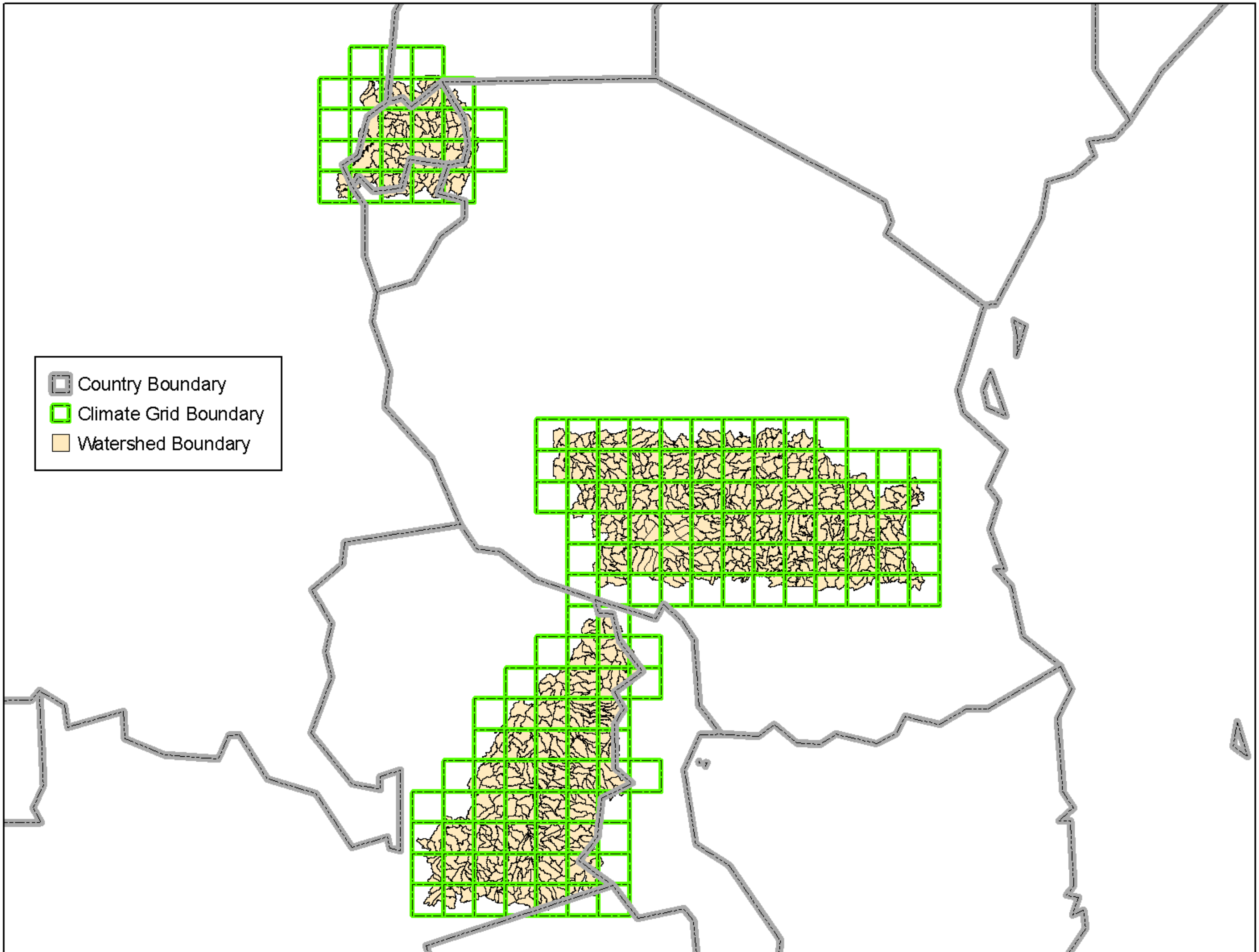
(Erika Cohen / Matt Wingard)

Overview

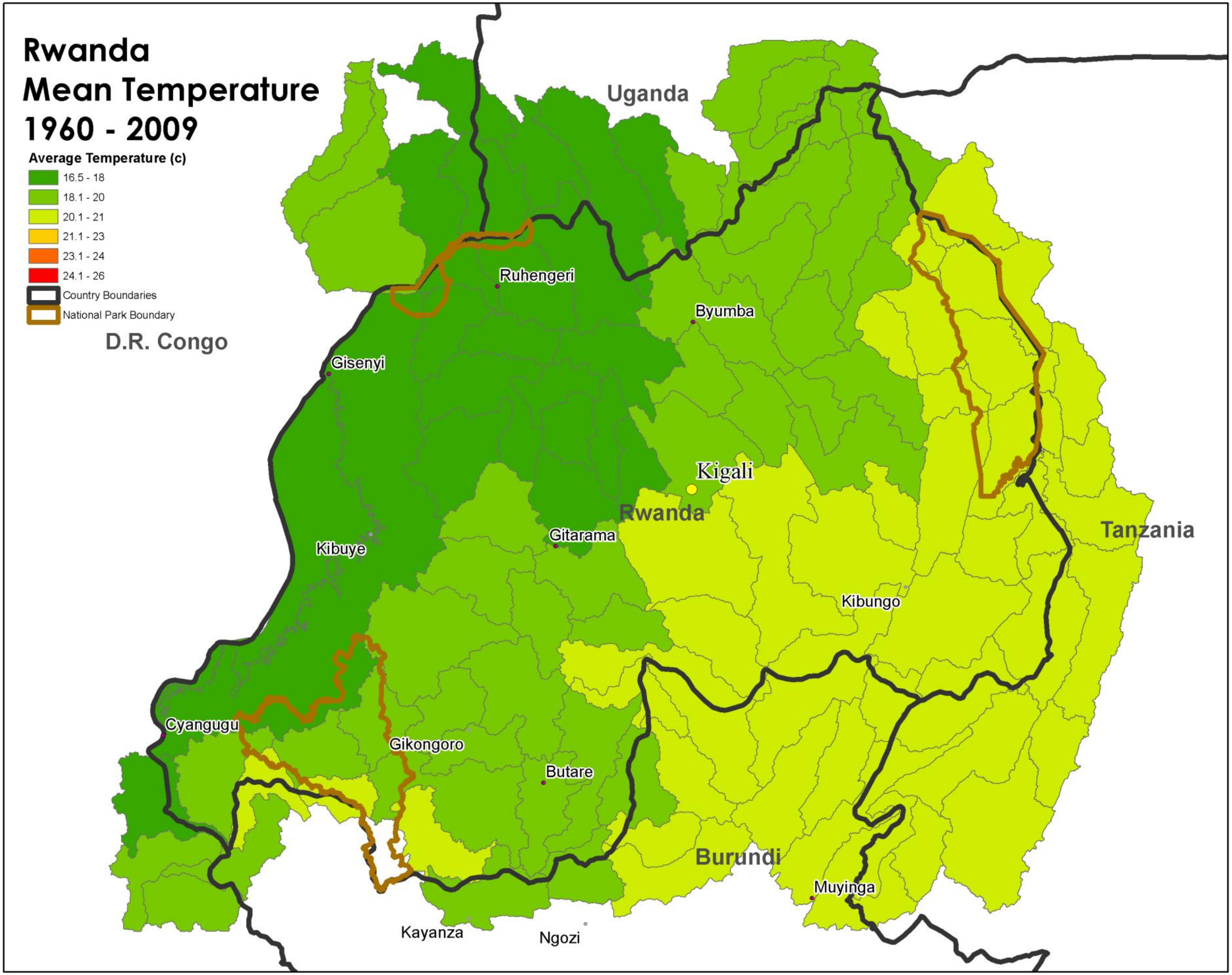
- Inputs
  - Dataset
    - Climate
    - Leaf Area Index (LAI)
    - Landcover
    - Sacramento Soil Moisture Accounting model
  - Format
  - Data Processing
- Outputs
  - Formats

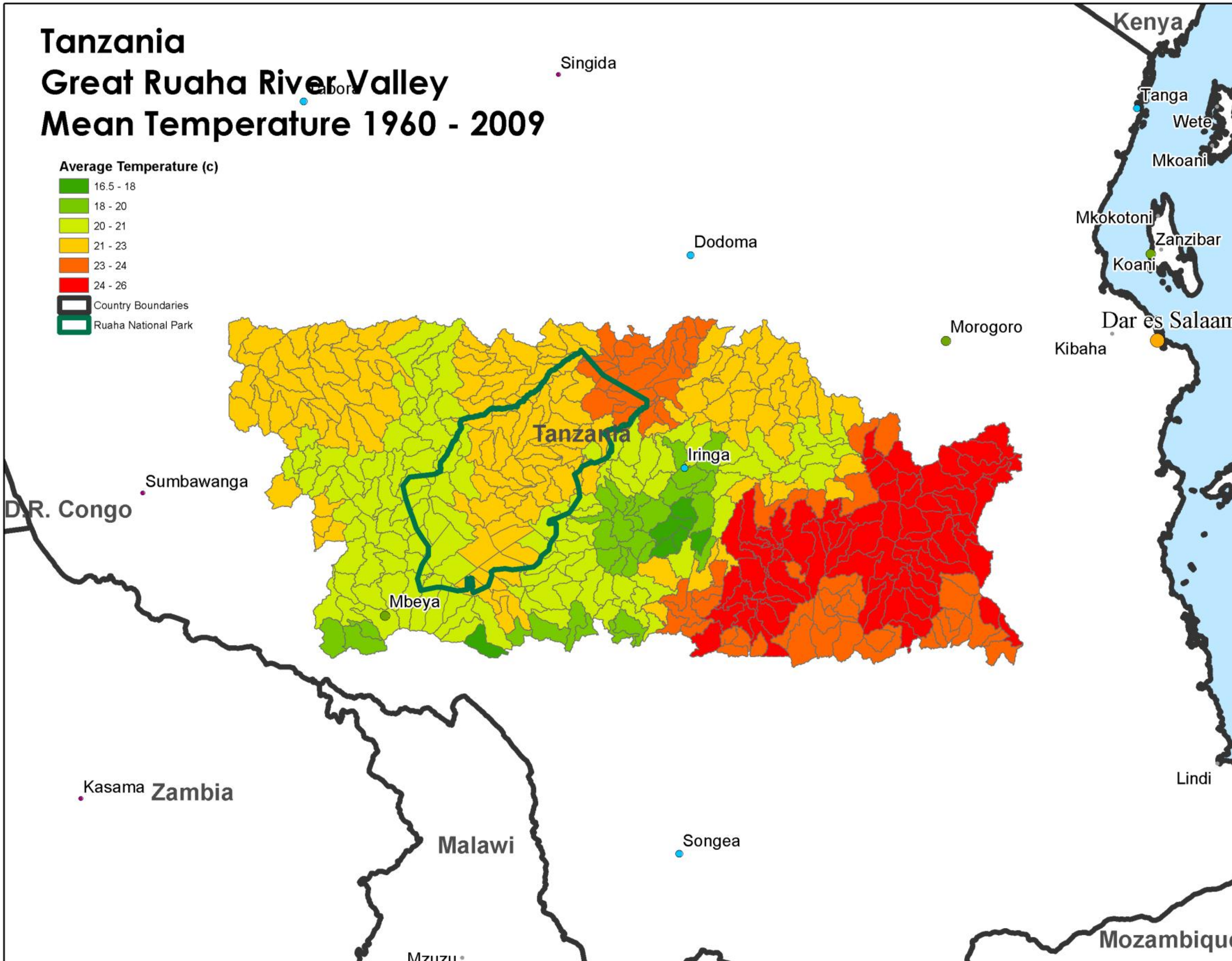
Climate Databases

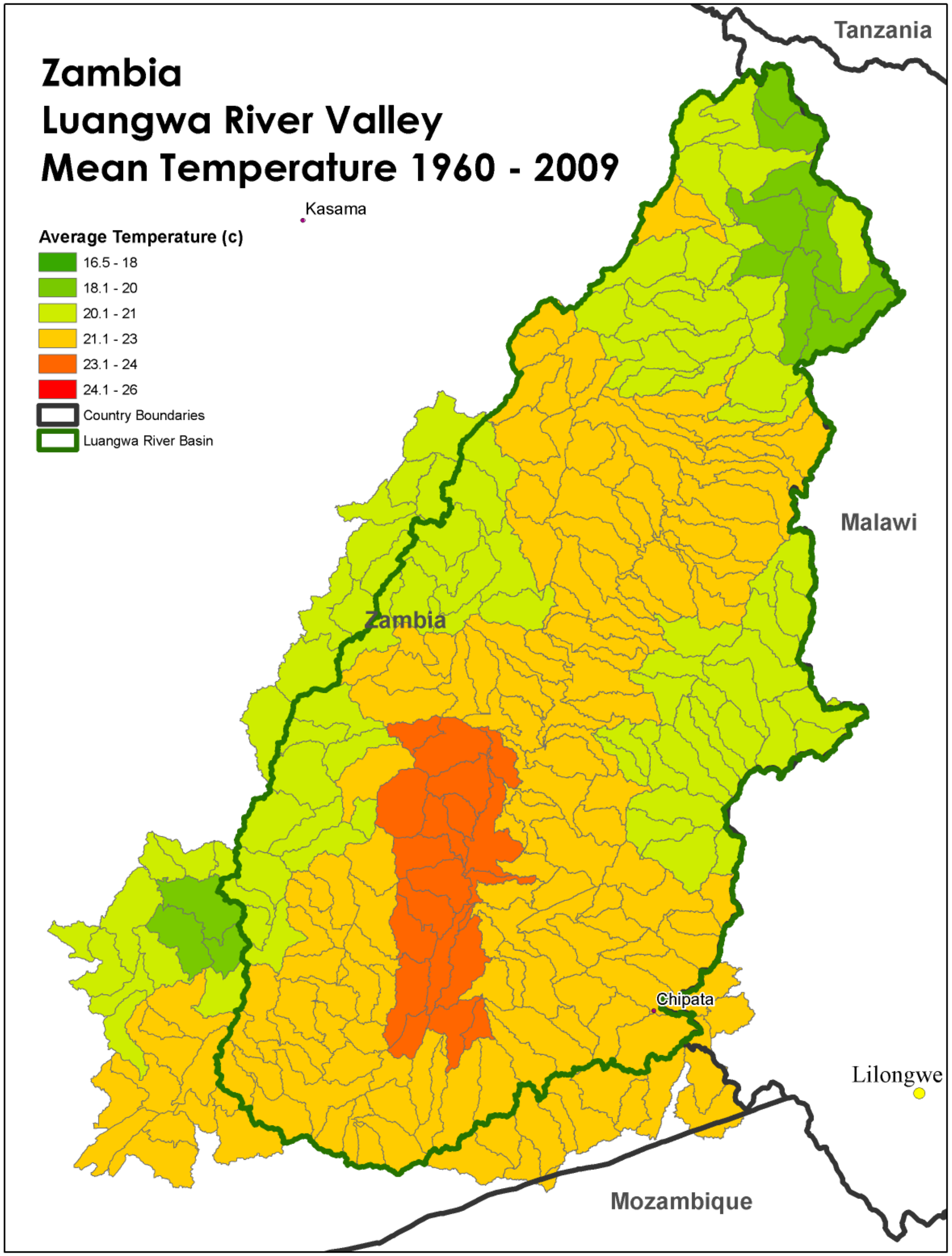
- Historic: CRU TS3.1
  - Climate Research Unit (CRU) Time-Series (TS) Dataset
  - The University of East Anglia
    - Version 3.1
    - Spatial Resolution: 0.5 x 0.5 Degree ~ 50 km^2
    - Temporal Resolution: 1901-2009
    - Time Step: Monthly
    - Variables: Minimum Temperature, Maximum Temperature, and Precipitation
    - Based on monthly mean temperat
- Future: Fixed changed
  - Precipitation: 20% Decrease
  - Temperature: 2 Degree Increase


Country Boundary
Climate Grid Boundary
Watershed Boundary

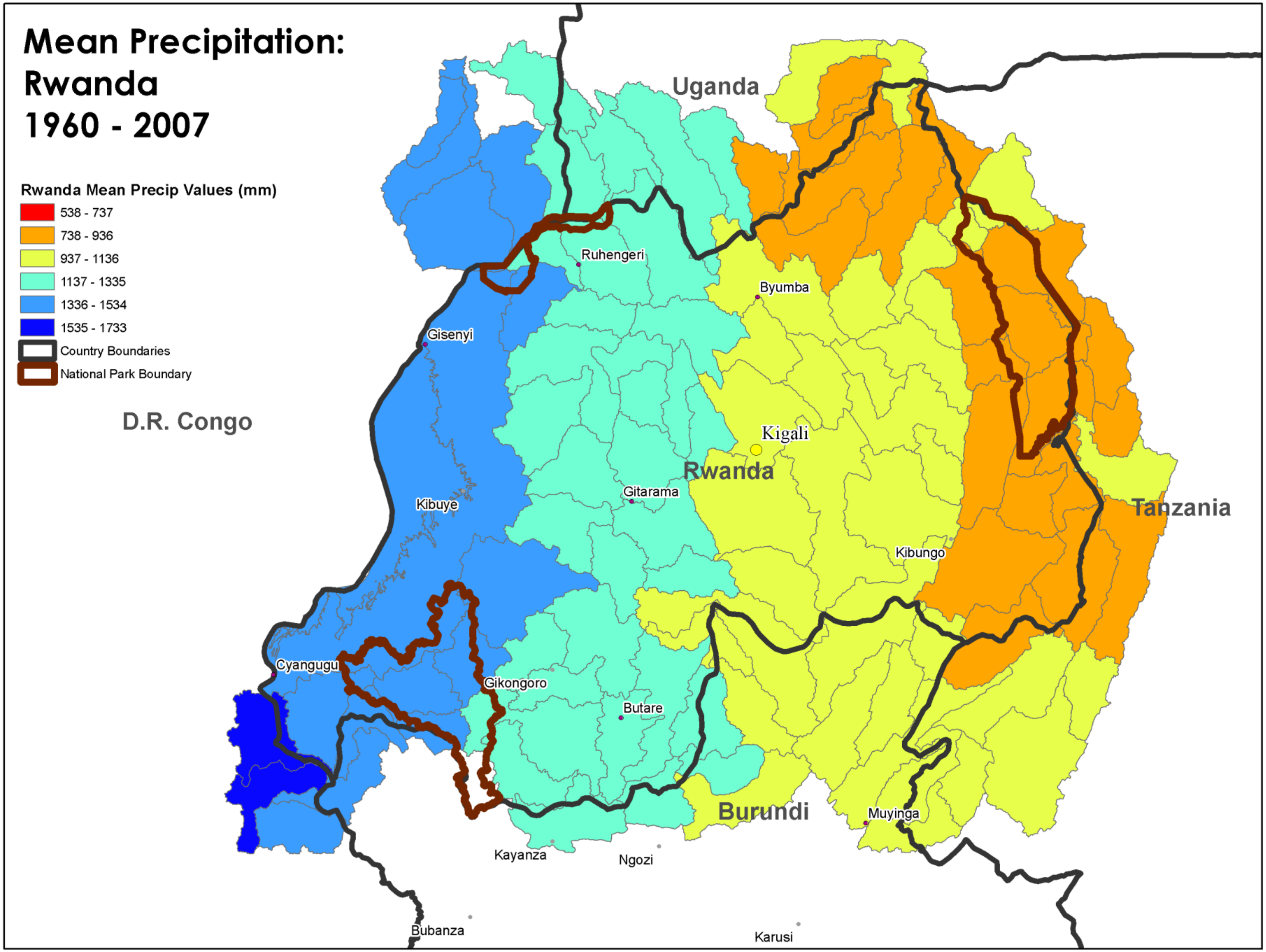
Average Annual Temperature Climate Maps


Rwanda
Mean Temperature
1960 - 2009
Average Temperature (c)
16.5 - 18
18.1 - 20
20.1 - 21
21.1 - 23
23.1 - 24
24.1 - 26
Country Boundaries
National Park Boundary
D.R. Congo
Uganda
Ruhengeri
Byumba
Gisenyi
Kigali
Rwanda
Gitarama
Kibuye
Tanzania
Kibungo
Cyangugu
Gikongoro
Butare
Burundi
Muyinga
Kayanza
Ngozi

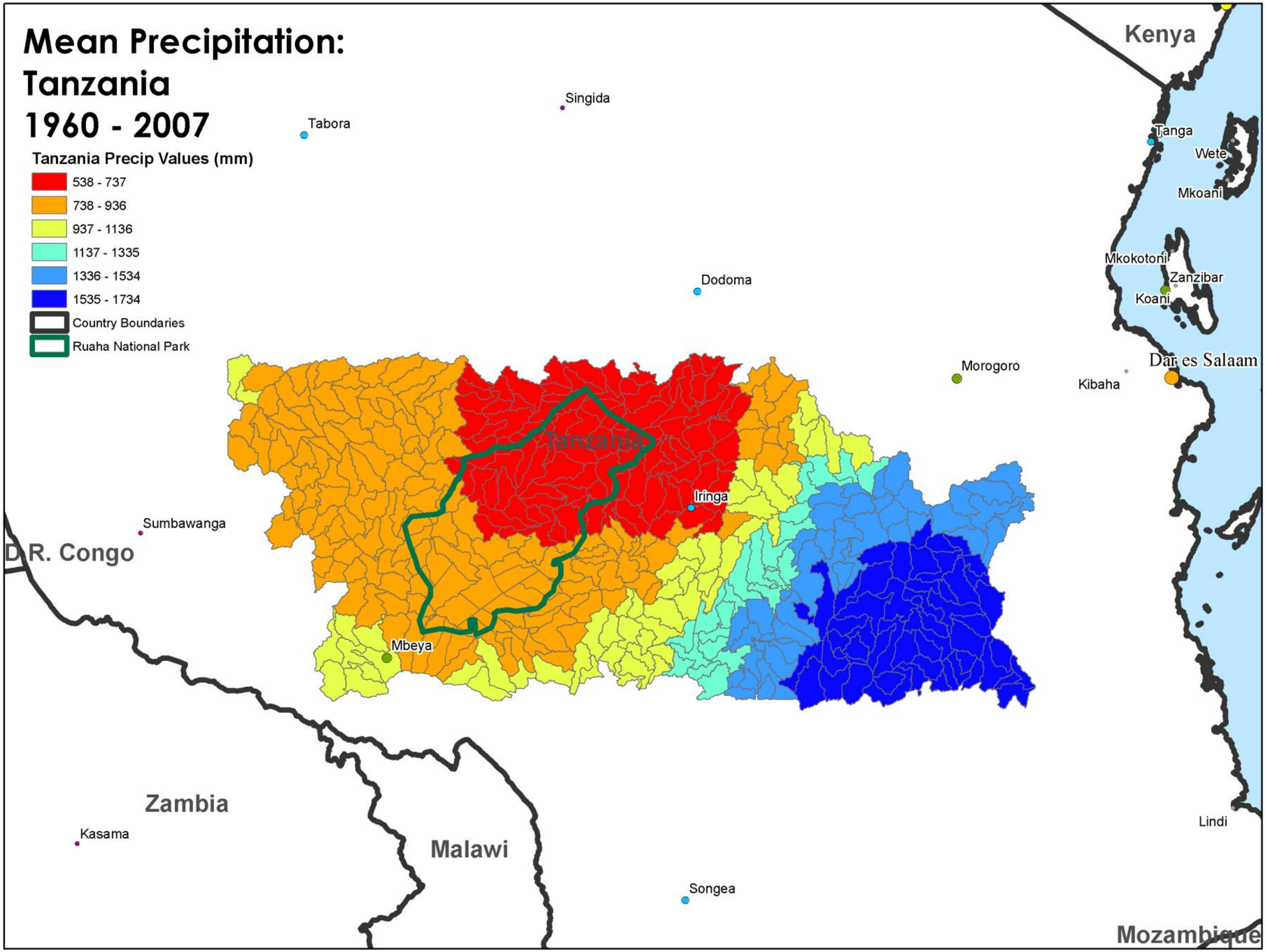

Tanzania
Great Ruaha River Valley
Mean Temperature 1960 - 2009
Average Temperature (c)
16.5 - 18
18 - 20
20 - 21
21 - 23
23 - 24
24 - 26
Country Boundaries
Ruaha National Park
Kenya
Singida
Tabora
Tanga
Wete
Mkoani
Mkokotoni
Zanzibar
Koani
Dodoma
Morogoro
Dar es Salaam
Kibaha
Tanzania
Iringa
Sumbawanga
D.R. Congo
Mbeya
Lindi
Kasama
Zambia
Malawi
Songea
Mzuzu
Mozambique


Zambia
Luangwa River Valley
Mean Temperature 1960 - 2009
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
Kasama
Tanzania
Malawi
Zambia
Chipata
Lilongwe
Mozambique

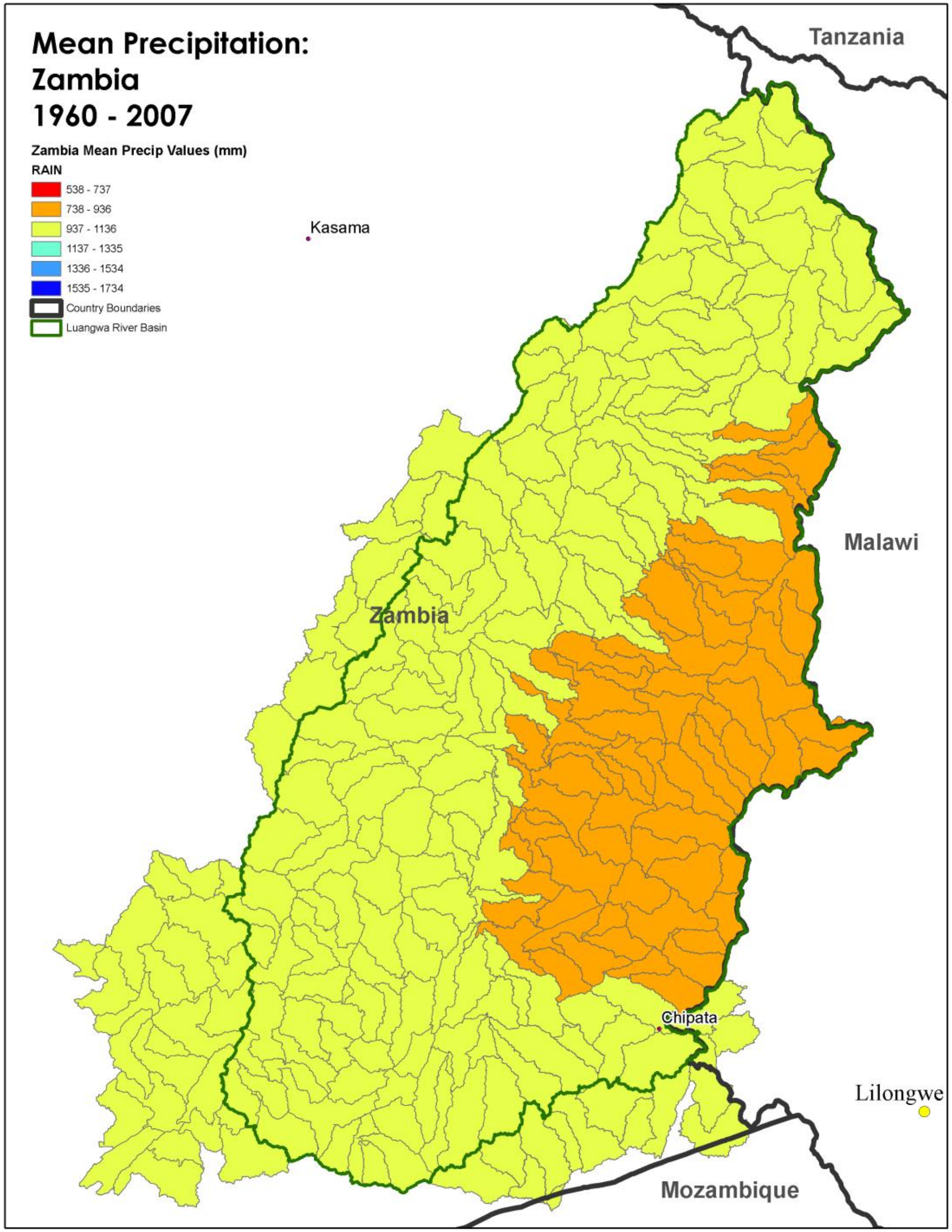
Average Precipitation Climate Maps



Mean Precipitation:
Rwanda
1960 - 2007
Rwanda Mean Precip Values (mm)
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1733
Country Boundaries
National Park Boundary
D.R. Congo
Uganda
Rwanda
Tanzania
Burundi
Ruhengeri
Byumba
Gisenyi
Kigali
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Kayanza
Ngozi
Bubanza
Karusi



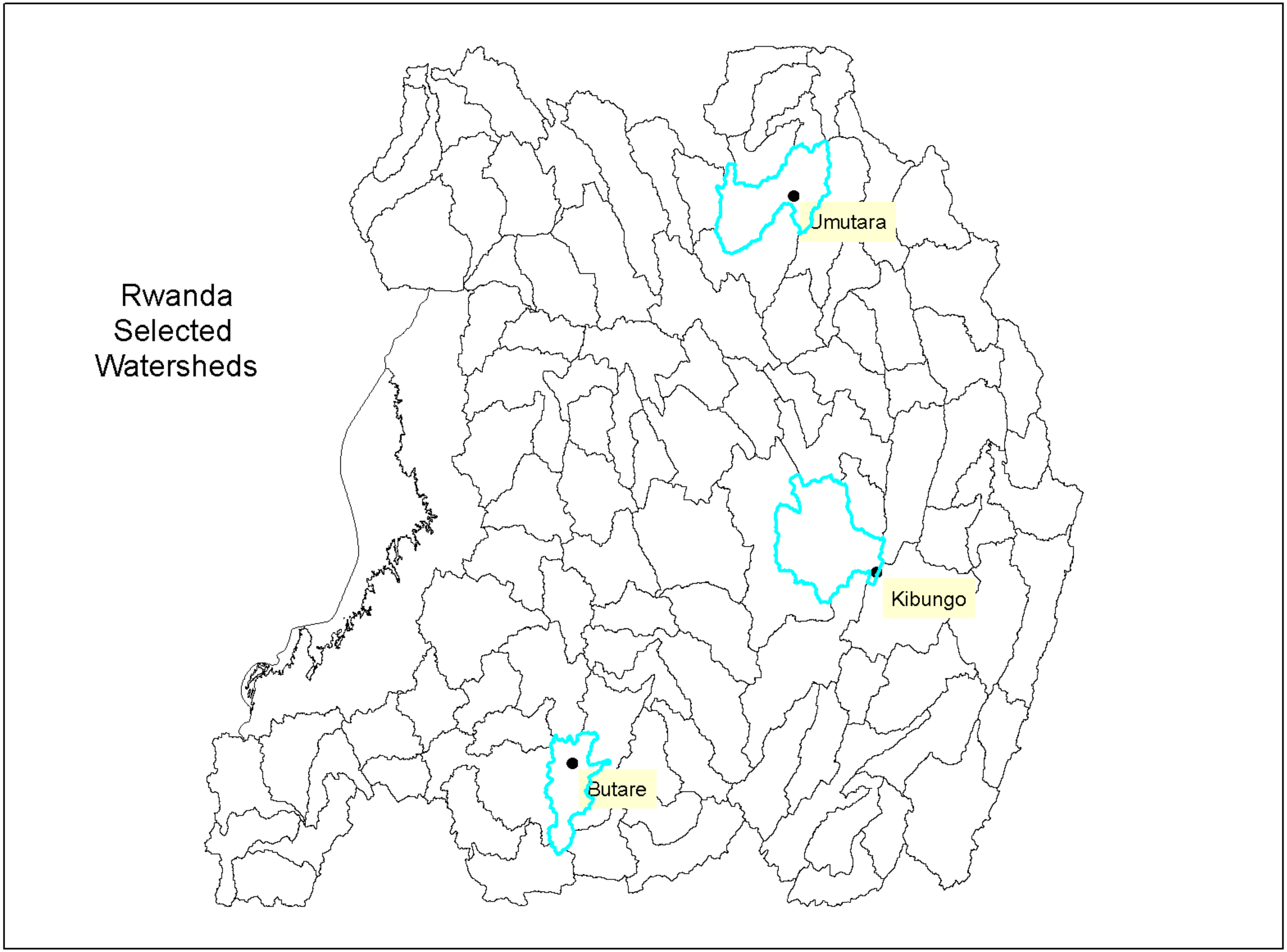
Mean Precipitation:
Tanzania
1960 - 2007
Tanzania Precip Values (mm)
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1734
Country Boundaries
Ruaha National Park
Kenya
Singida
Tabora
Tanga
Wete
Mkoani
Mkokotoni
Zanzibar
Koani
Dodoma
Morogoro
Kibaha
Dar es Salaam
Tanzania
Iringa
Sumbawanga
D.R. Congo
Mbeya
Zambia
Kasama
Malawi
Songea
Lindi
Mozambique



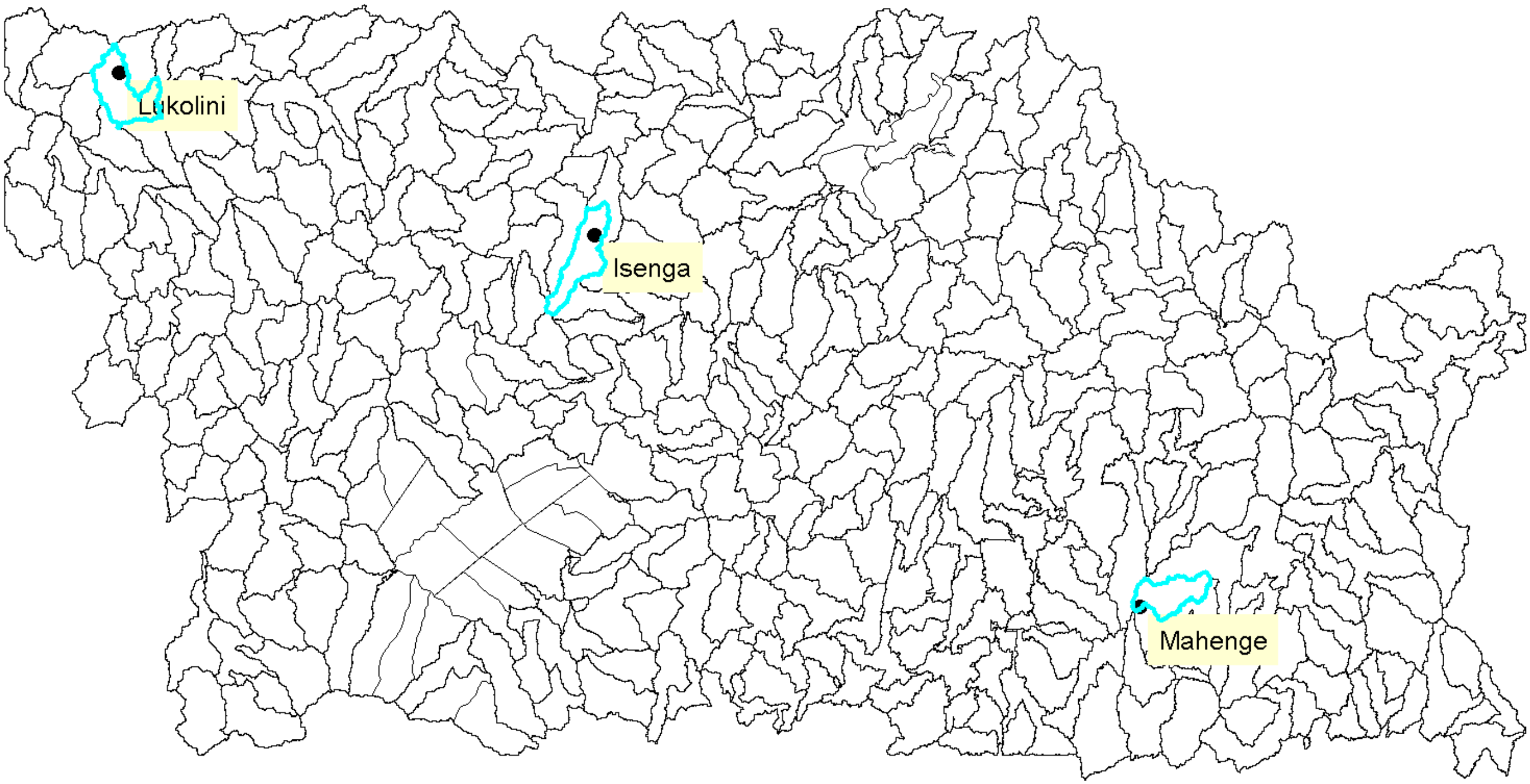
Mean Precipitation:
Zambia
1960 - 2007
Zambia Mean Precip Values (mm)
RAIN
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1734
Country Boundaries
Luangwa River Basin
Tanzania
Kasama
Malawi
Zambia
Chipata
Lilongwe
Mozambique

Climate Over Time

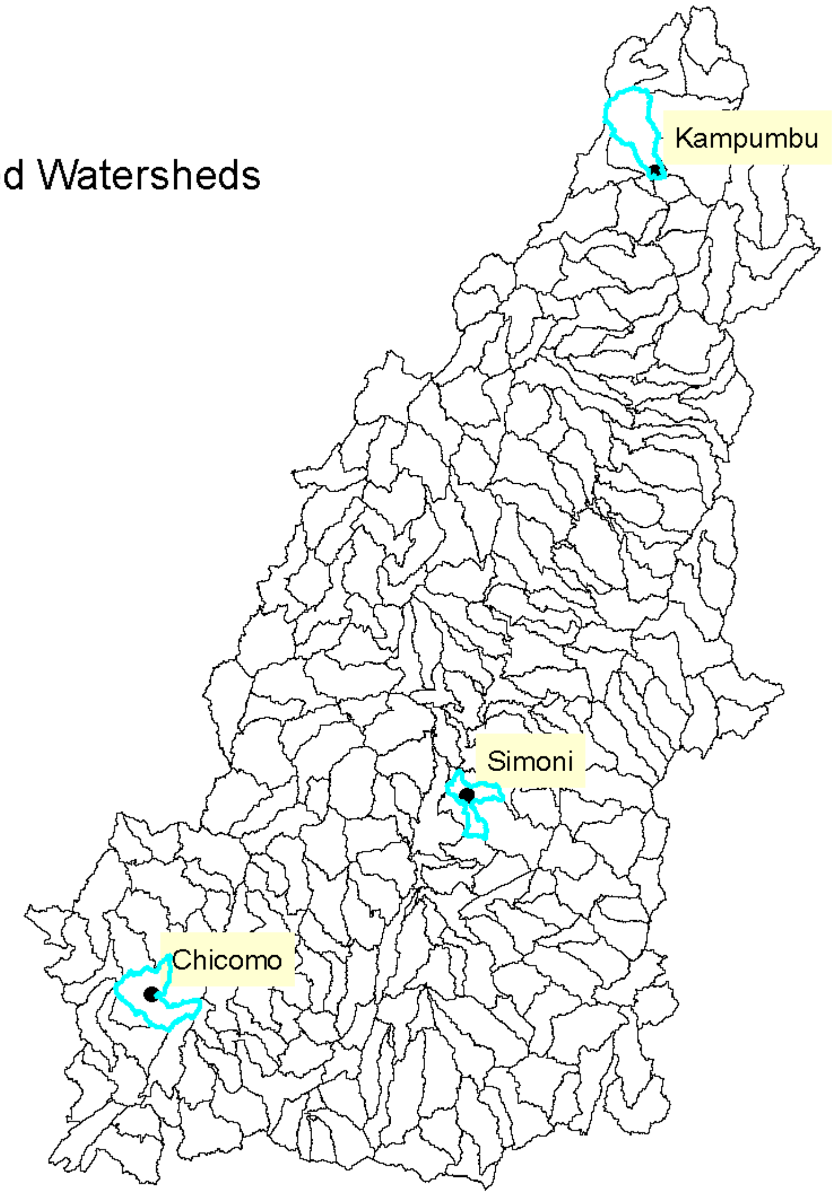
- Site Examples
  - Three watershed selected in each country
  - Rwanda
    - Butara, Kibungo, Umutana
  - Tanzania
    - Isenga, Lukolini, Mahenge
  - Zambia
    - Chicomo, Simoni, Kampumbu
- Average Annual Temperature
- Annual Precipitation

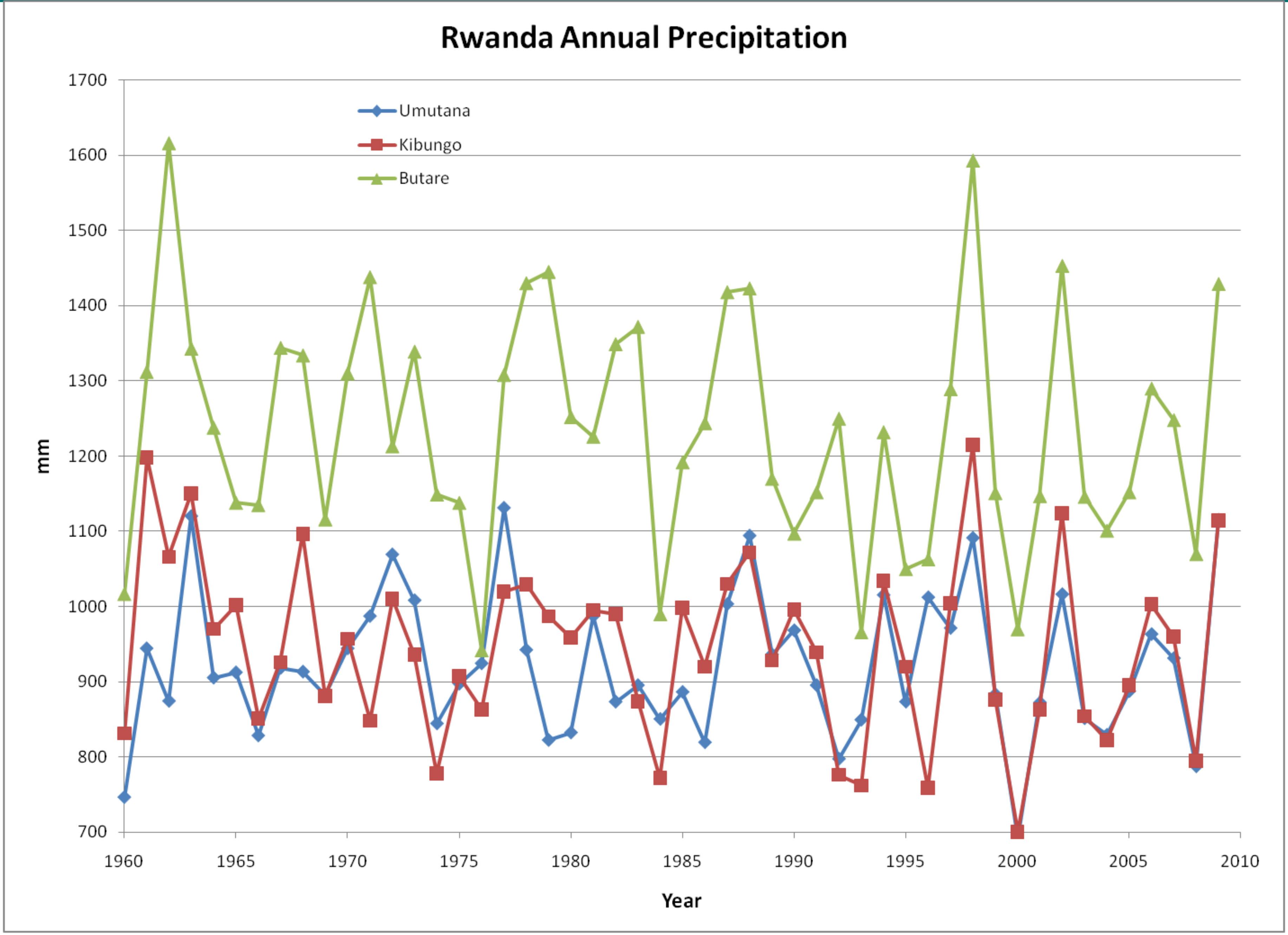

Rwanda
Selected
Watersheds
Umutara
Kibungo
Butare

Tanzania Selected Watersheds

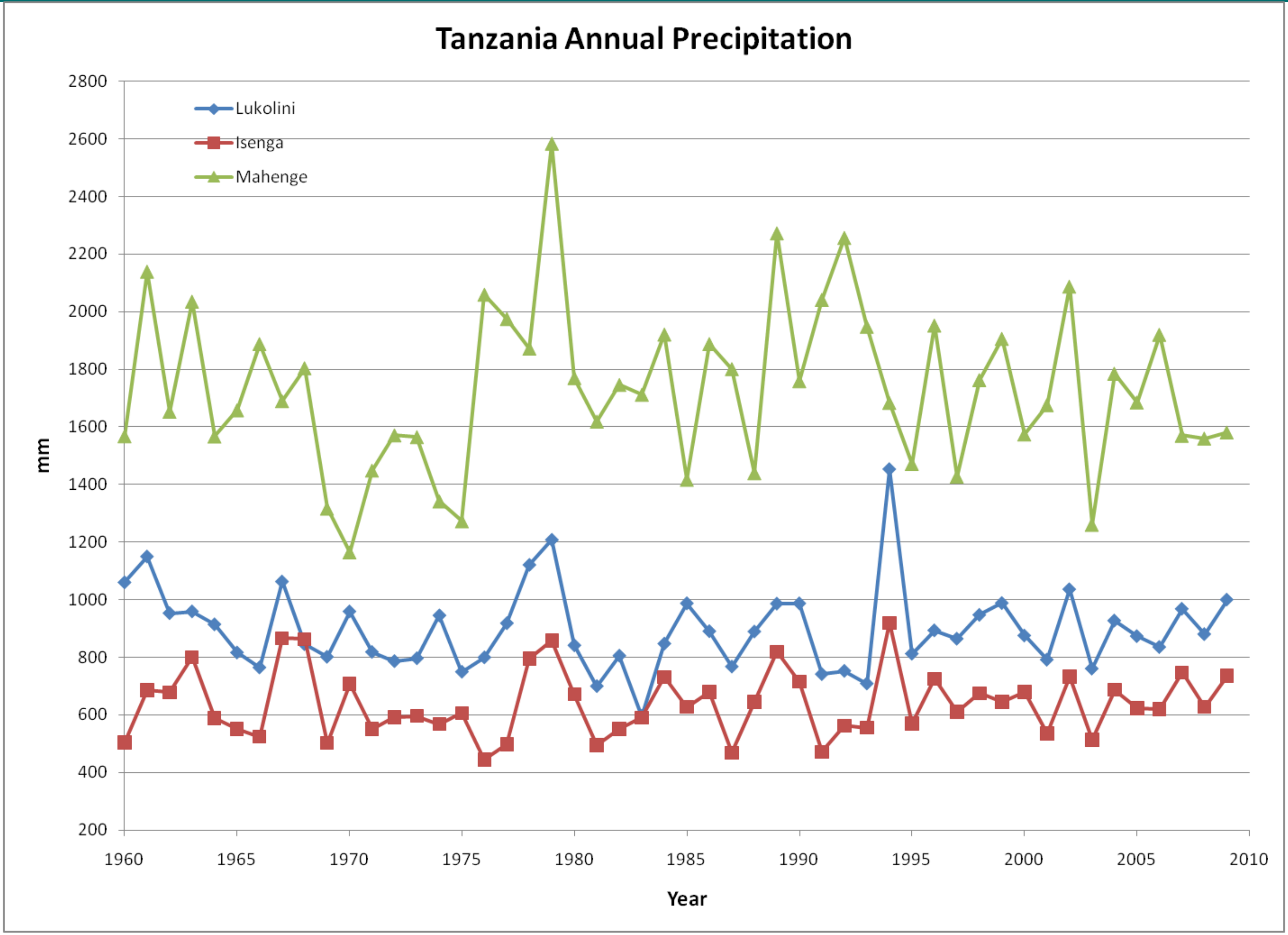


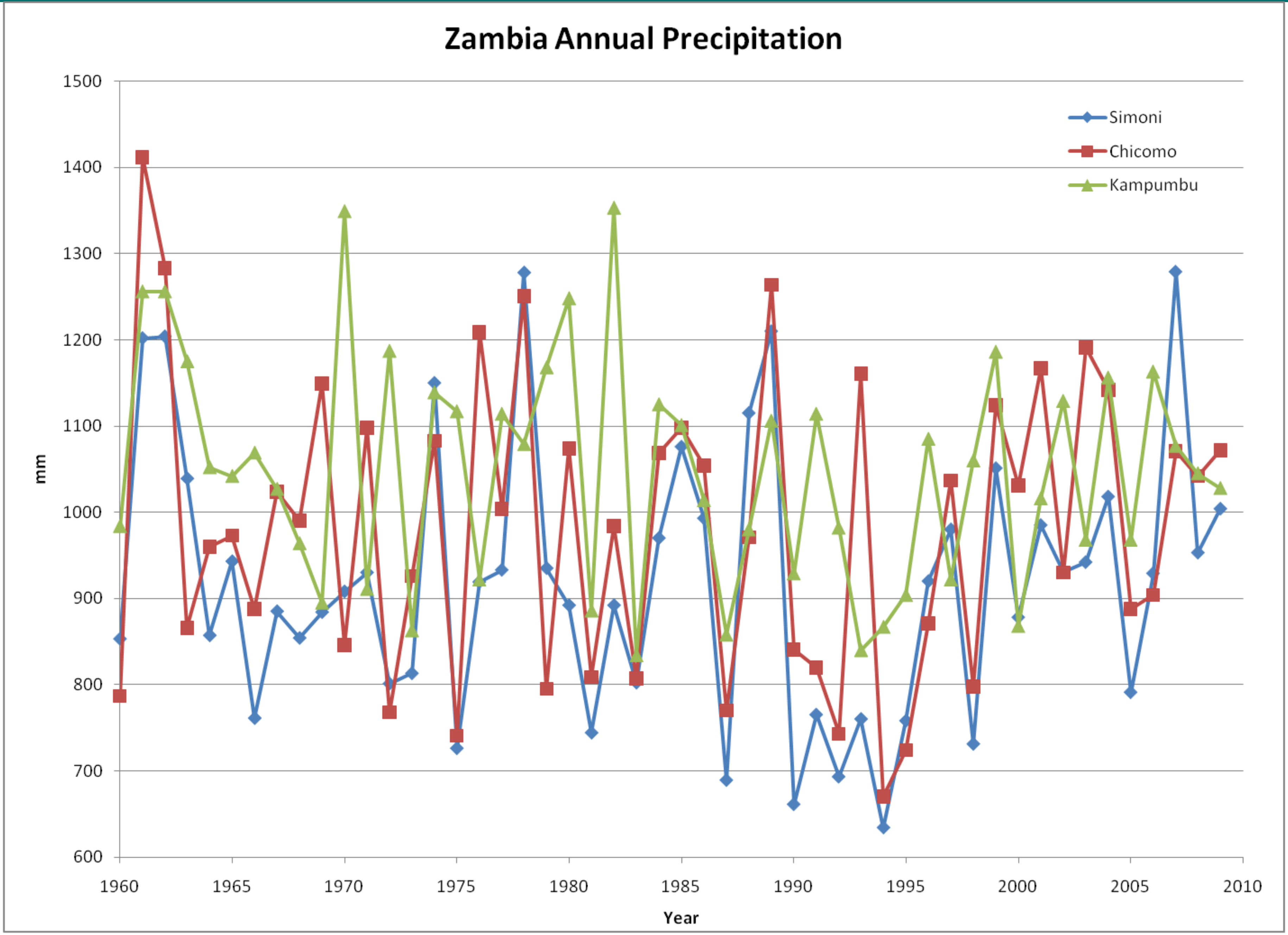
Zambia Selected Watersheds

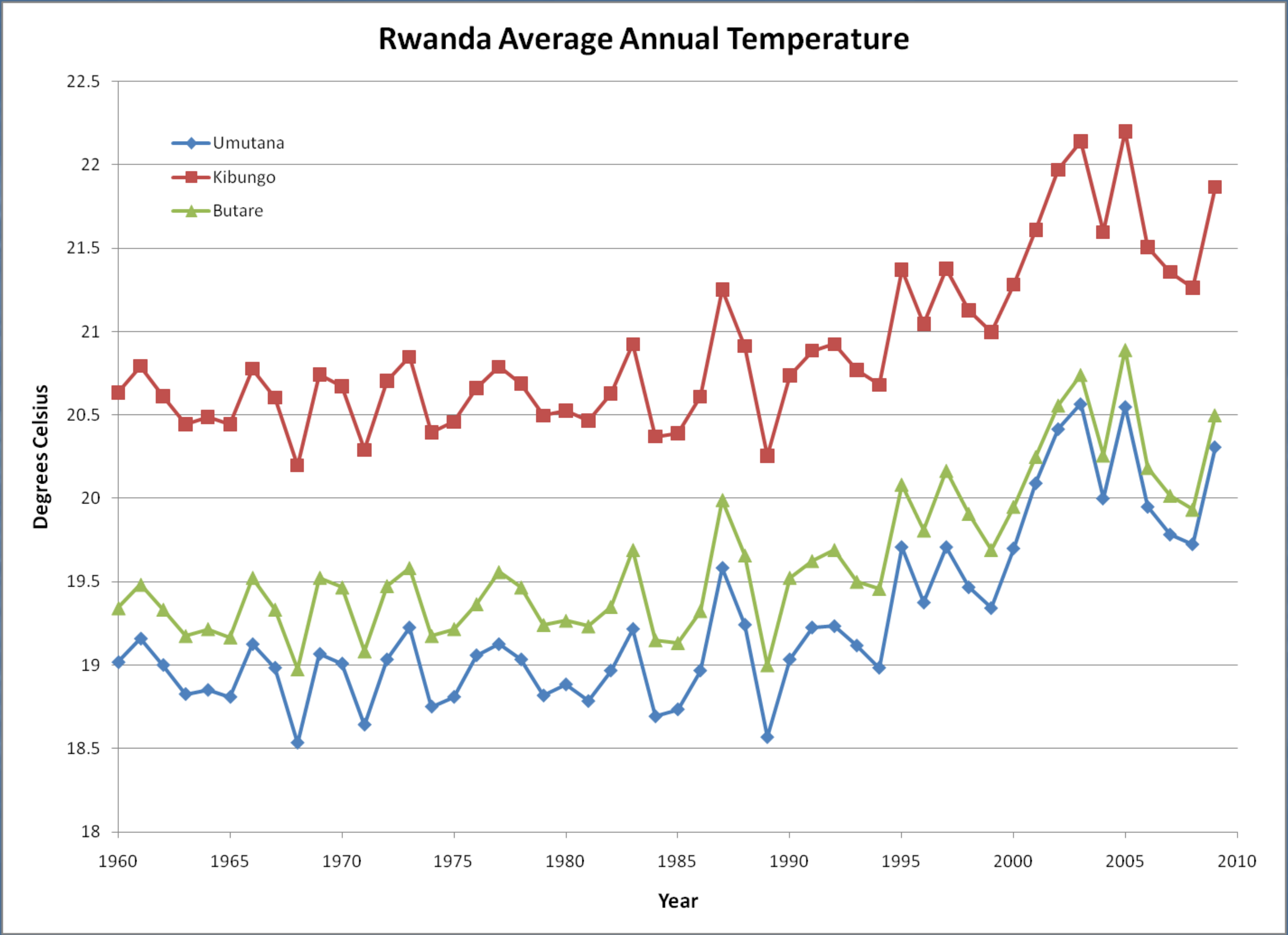


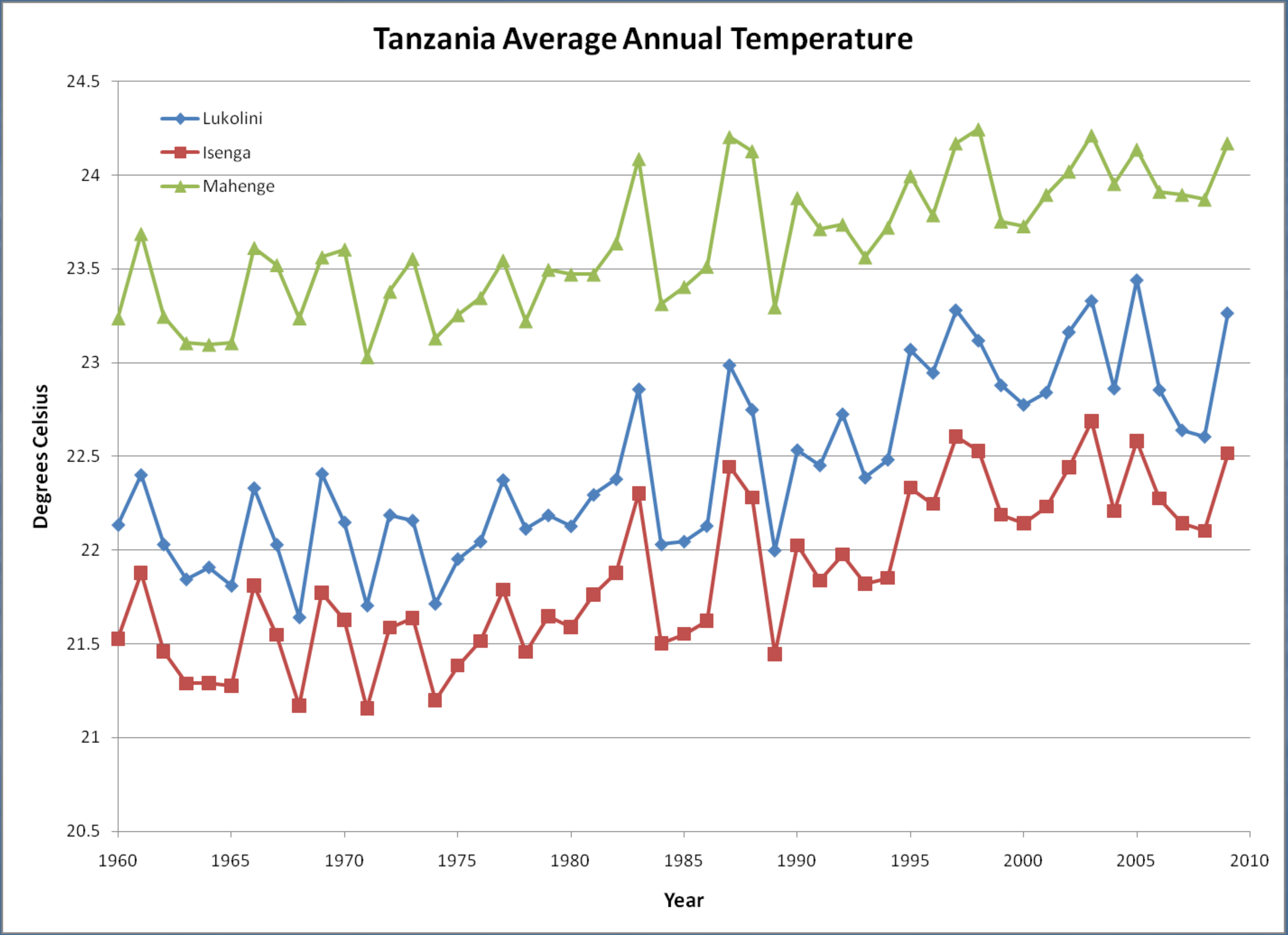


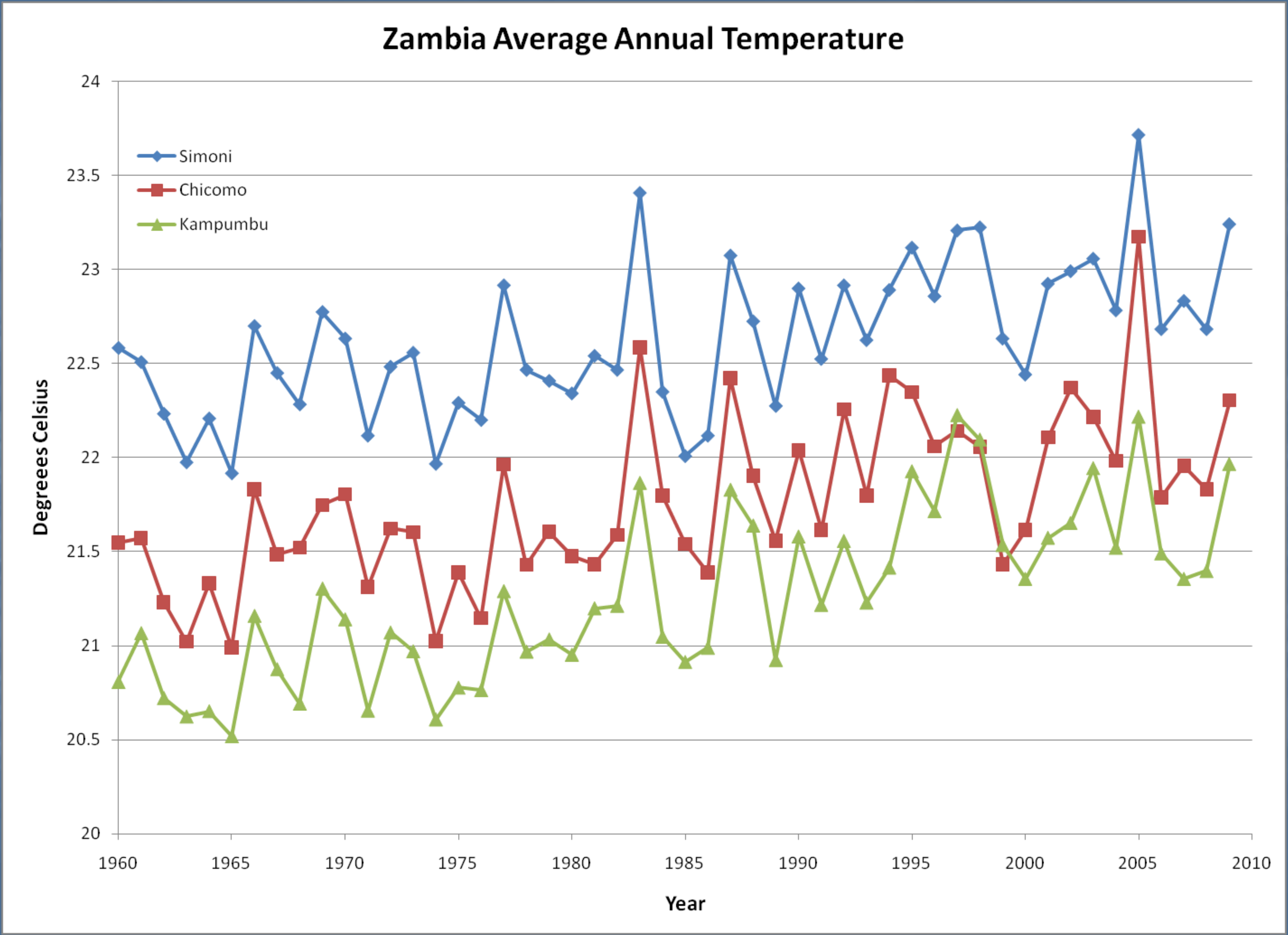
Rwanda Annual Precipitation
Umutana
Kibungo
Butare
mm
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year


Tanzania Annual Precipitation
Lukolini
Isenga
Mahenge
mm
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year


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

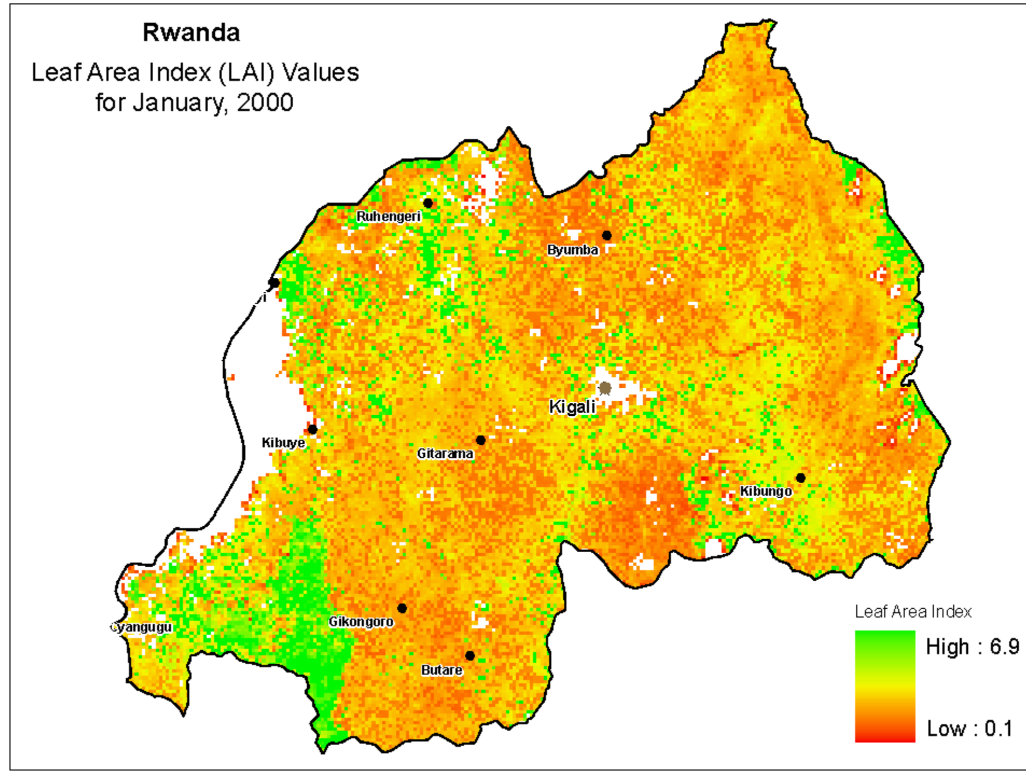

Rwanda Average Annual Temperature
Umutana
Kibungo
Butare
Degrees Celsius
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

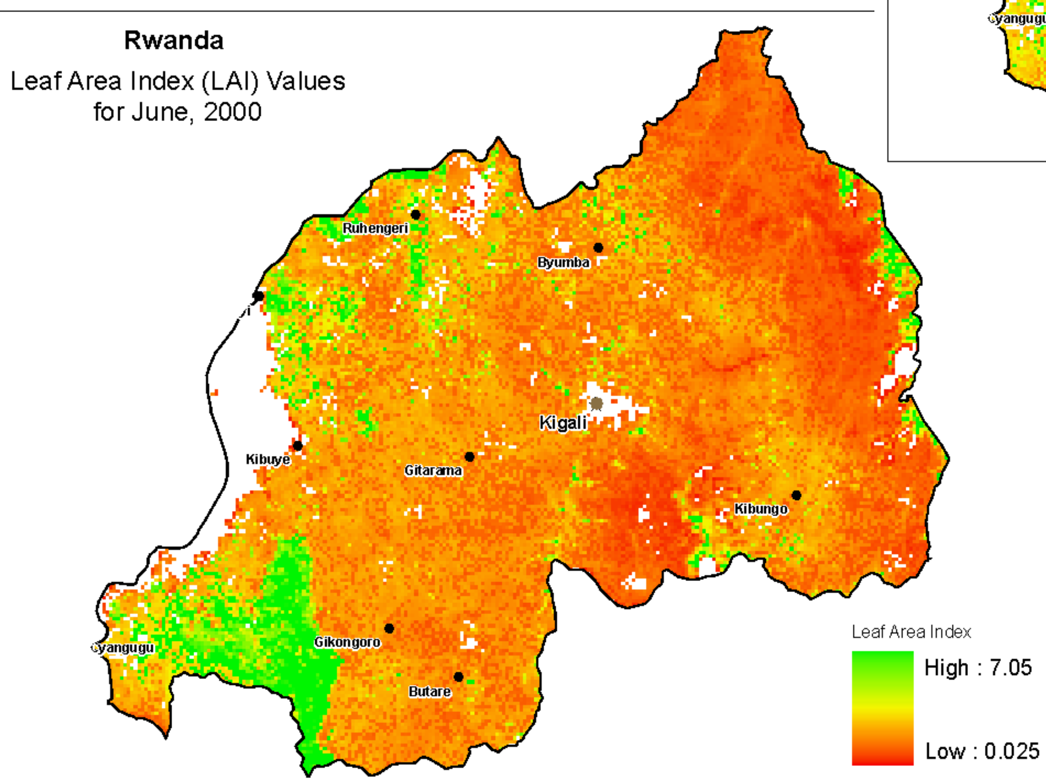

Tanzania Average Annual Temperature
Lukolini
Isenga
Mahenge
Degrees Celsius
24.5
24
23.5
23
22.5
22
21.5
21
20.5
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year


Zambia Average Annual Temperature
Simoni
Chicomo
Kampumbu
Degreees Celsius
24
23.5
23
22.5
22
21.5
21
20.5
20
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

Improved Leaf Area Index (LAI)

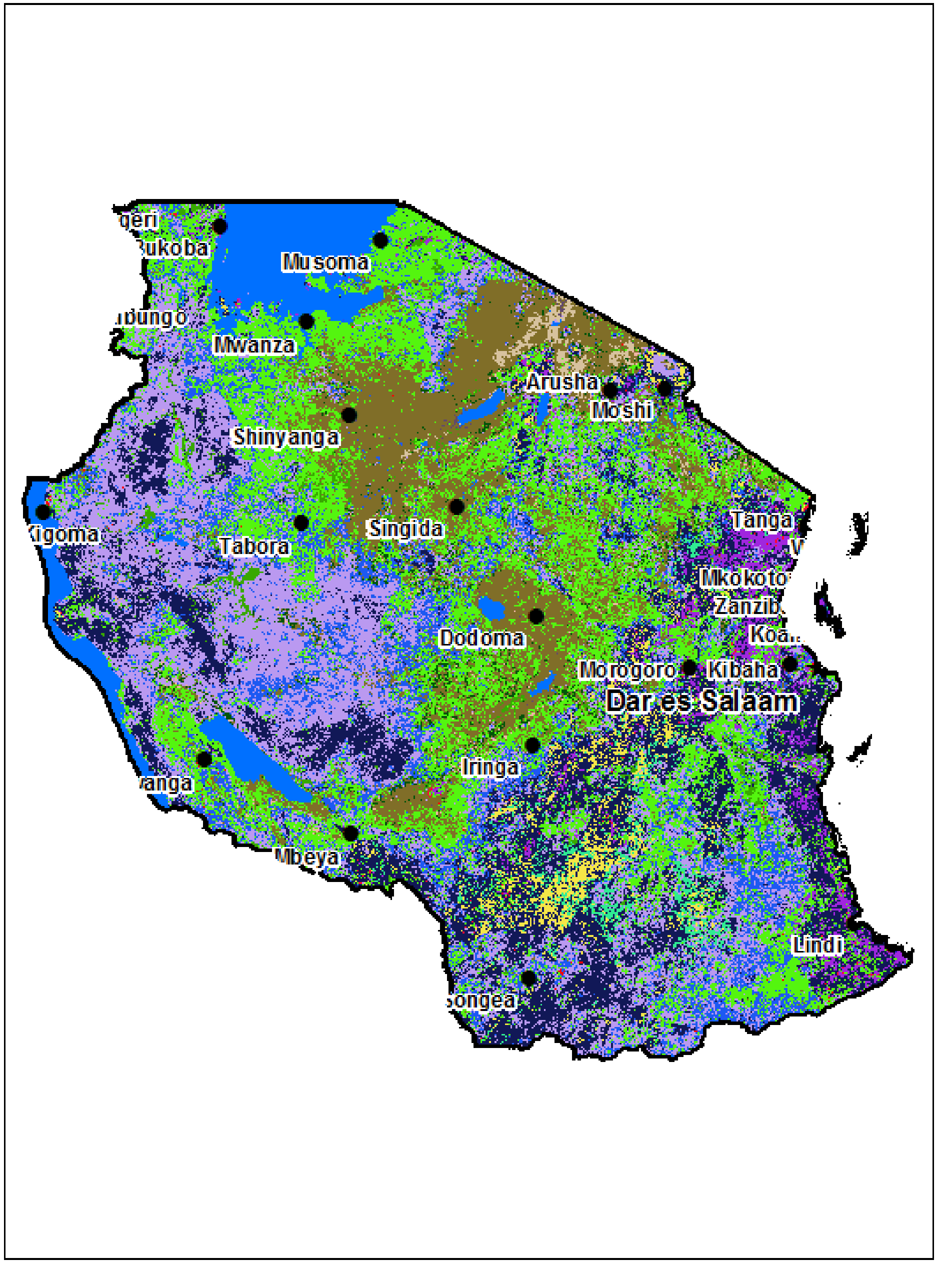
- Zhao et al.,2005
  - Numerical Terradynamic Simulation Group (NTSG) at the University of Montana Missoula
    - Source: MODIS Imagery, MOD15(FPAR/LAI)
    - Spatial Resolution: 1 km^2
    - Temporal Resolution: 2000-2006
    - Time Step: Monthly
- Zhao et al fill cloud-contaminated pixels
- LAI is used to calculate evapotranspiration in WaSSI-CB


Rwanda
Leaf Area Index (LAI) Values
for January, 2000
Ruhengeri
Byumba
Kigali
Kibuye
Gitarama
Kibungo
Gikongoro
Butare
Leaf Area Index
High : 6.9
Low : 0.1


Rwanda
Leaf Area Index (LAI) Values
for June, 2000
Ruhengeri
Byumba
Kigali
Kibuye
Gitarama
Kibungo
Gikongoro
Butare
Leaf Area Index
High : 7.05
Low : 0.025

Land Cover

- Globcover
  - European Space Agency (ESA), MERIS instrument
- Spatial Resolution
  - 300 m^2
- Temporal Resolution
  - 2006 composite
    - Dec. 2004 – Jun. 2006
  - 2009 composite
    - Jan. 1 2009 – Dec. 2009
- Land Cover Classes
  - Global Legend: 22 classes
  - Regional Legend: > 22 classes
  - UN Land Cover Classification System compatible with GLC2000 classification



Tanzania

300 meter resolution Land Cover Globcover Dataset 2009

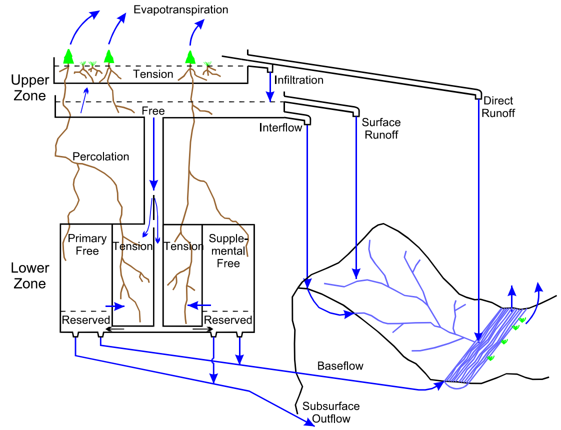
Land Cover Types

- 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

NOAA-NWS Sacramento Soil-Moisture Accounting model (SAC-SMA)

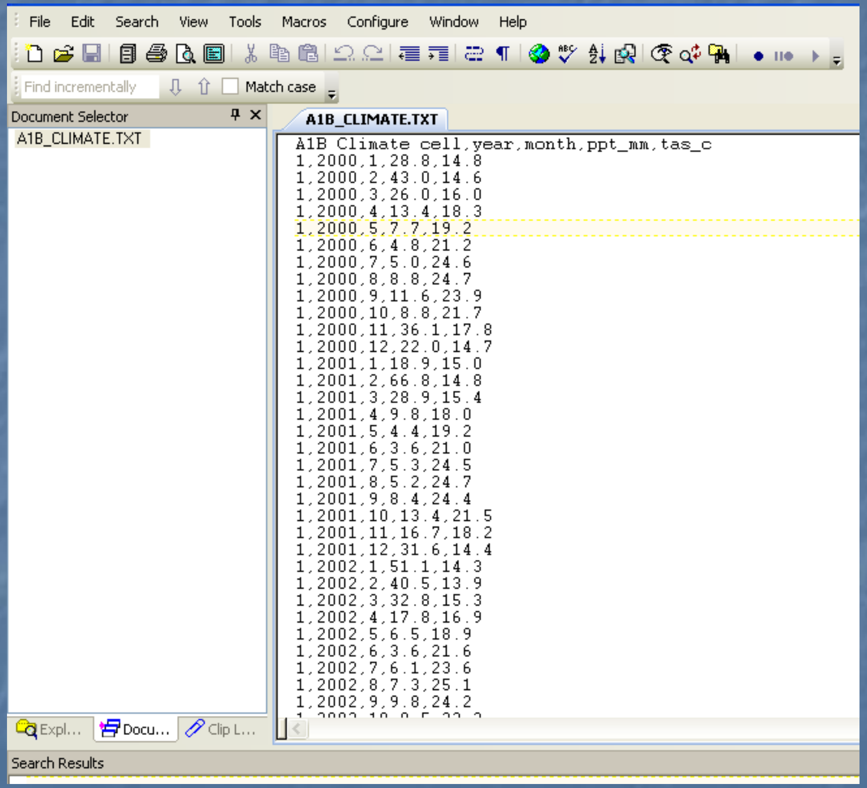
- Used for decades for flood forecasting in smaller watersheds
- 11 soil parameters over 2 soil layers
  - Water storage capacities
  - Vertical/lateral flow rates
- Parameters derived by model calibration
- NWS provided gridded parameters based on STATSGO soil data

➢Sacramento Soil-Moisture Accounting model



Input Format

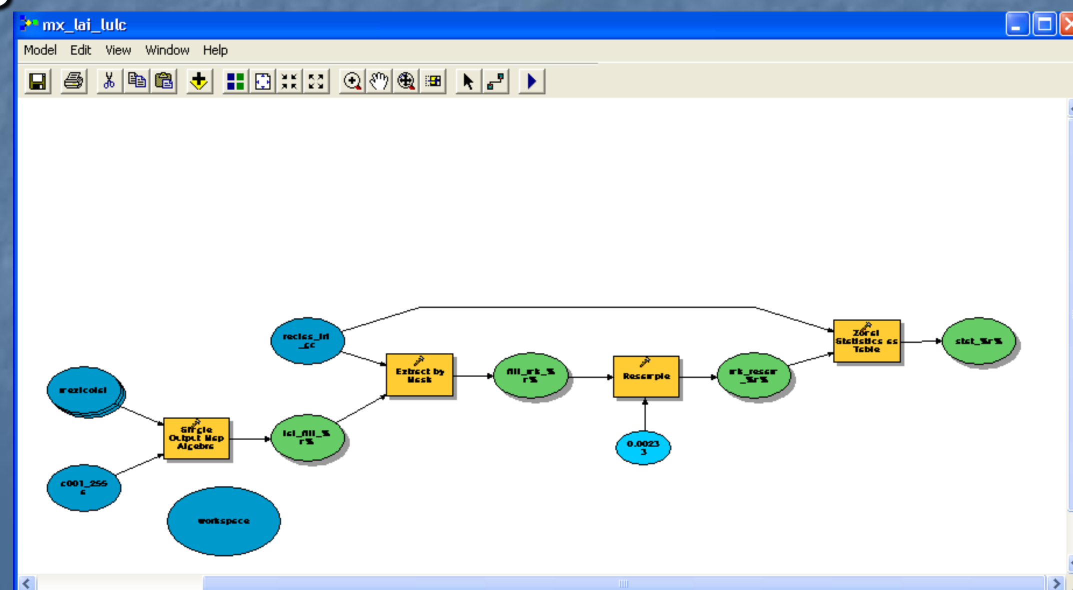
- Five Comma delimited text file
  - General
  - CellInfo
  - LandLAI
  - SoilInfo
  - Climate

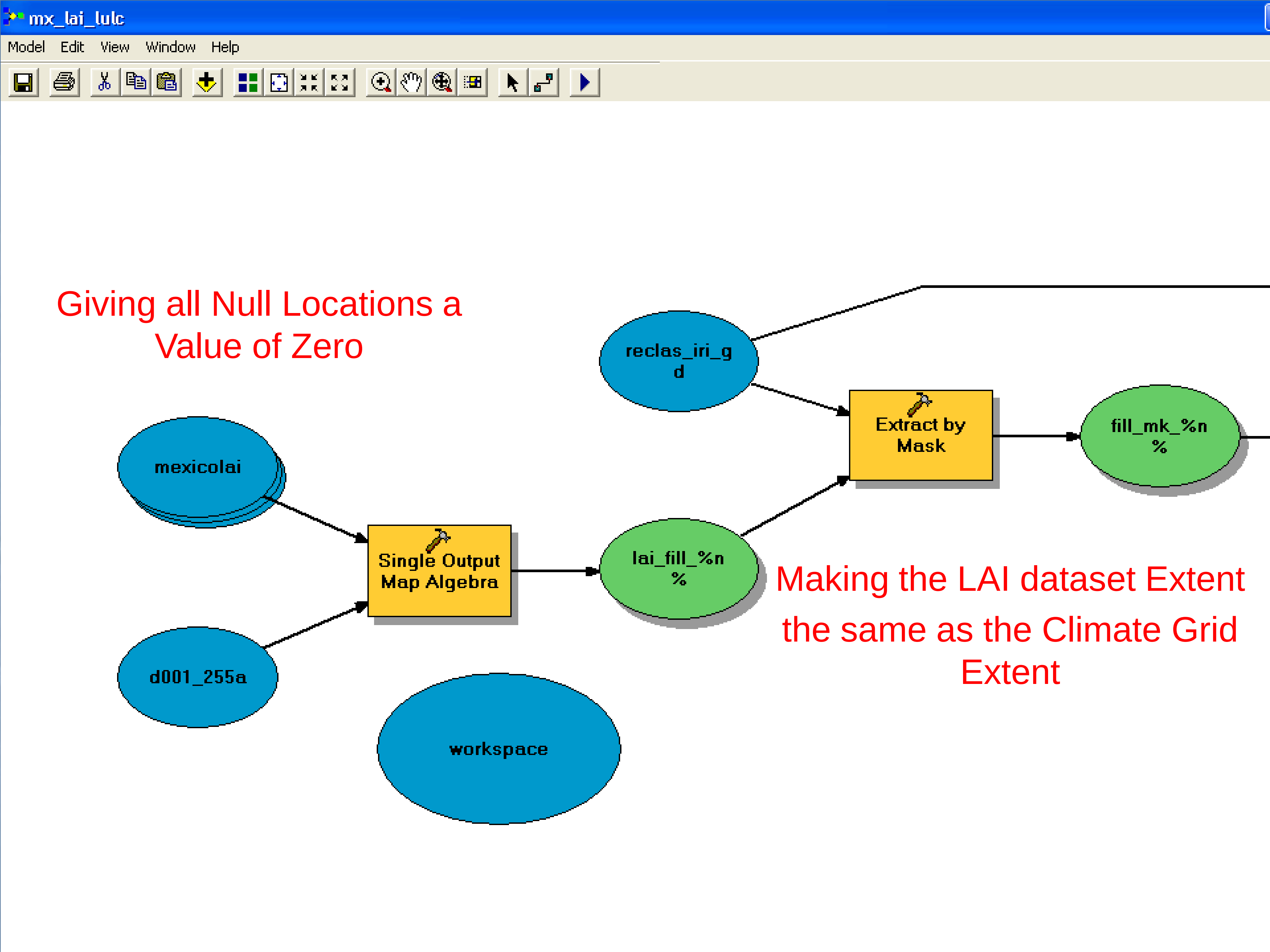


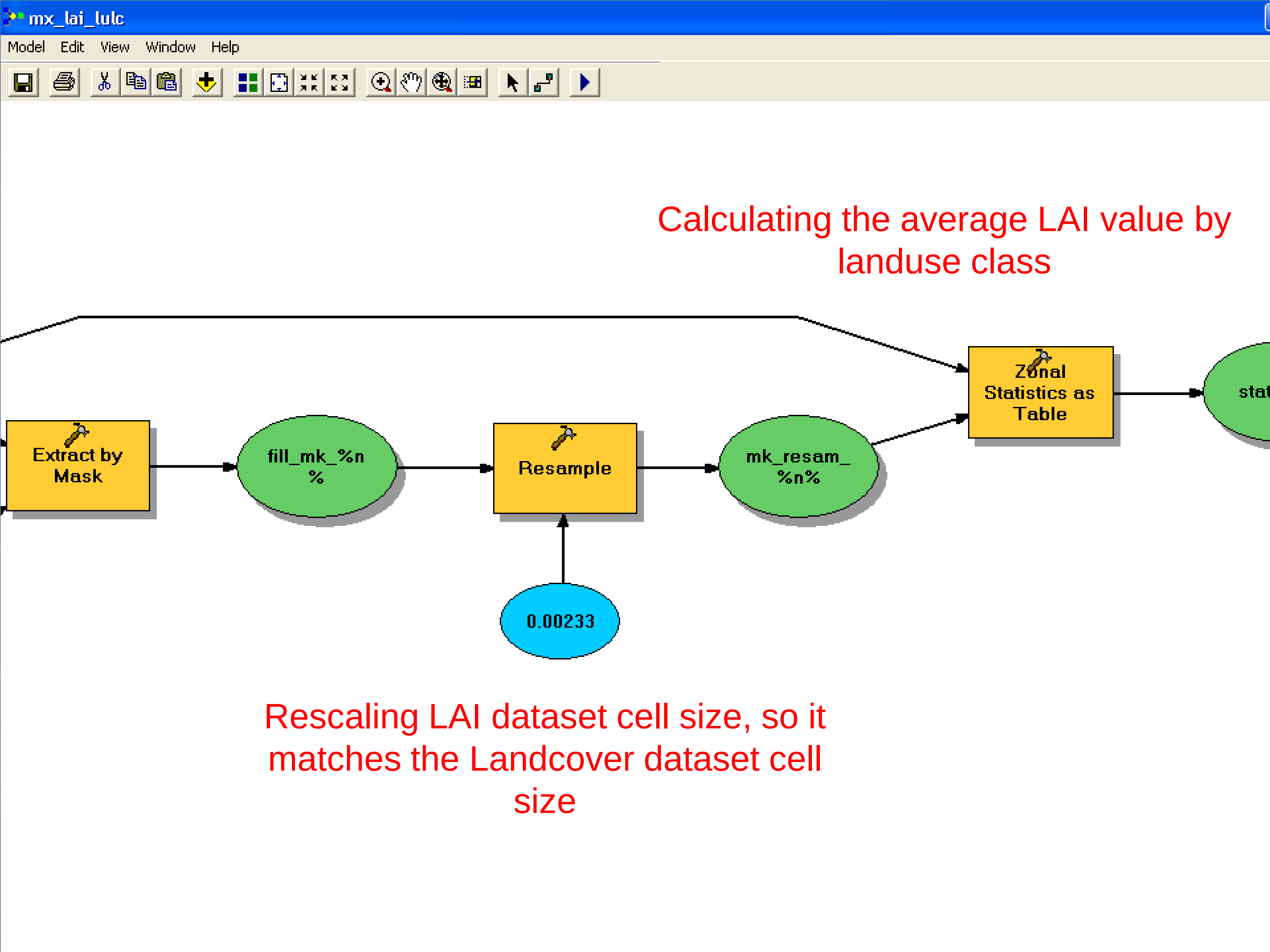
- Sorted by Watershed, Year, Month

Input Processing

- Processing Tools used to create convert data from original format to textfiles
  - GIS Models
  - Python Scripts
  - Microsoft Access
  - SQL Server
  - Rescaling Data




mx_lai_lulc
Model Edit View Window Help
Giving all Null Locations a Value of Zero
reclas_iri_gd
Extract by Mask
fill_mk_%n%
mexicolai
Single Output Map Algebra
lai_fill_%n%
d001_255a
workspace
Making the LAI dataset Extent the same as the Climate Grid Extent



Calculating the average LAI value by landuse class

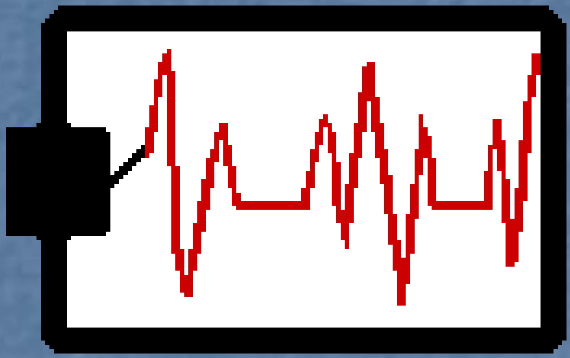
Rescaling LAI dataset cell size, so it matches the Landcover dataset cell size

Output Format

- Nine Text Files
  - Basicout
  - Monthrunoff
  - Monthcarbon
  - Annualflow
  - Annualcarbon
  - Annualbio
  - Hucflow
  - Huccarbon
  - Hucbio

Output Presentation

- Charts
  - Excel
- Maps
  - ArcGIS
    - Text files joined to geospatial layer



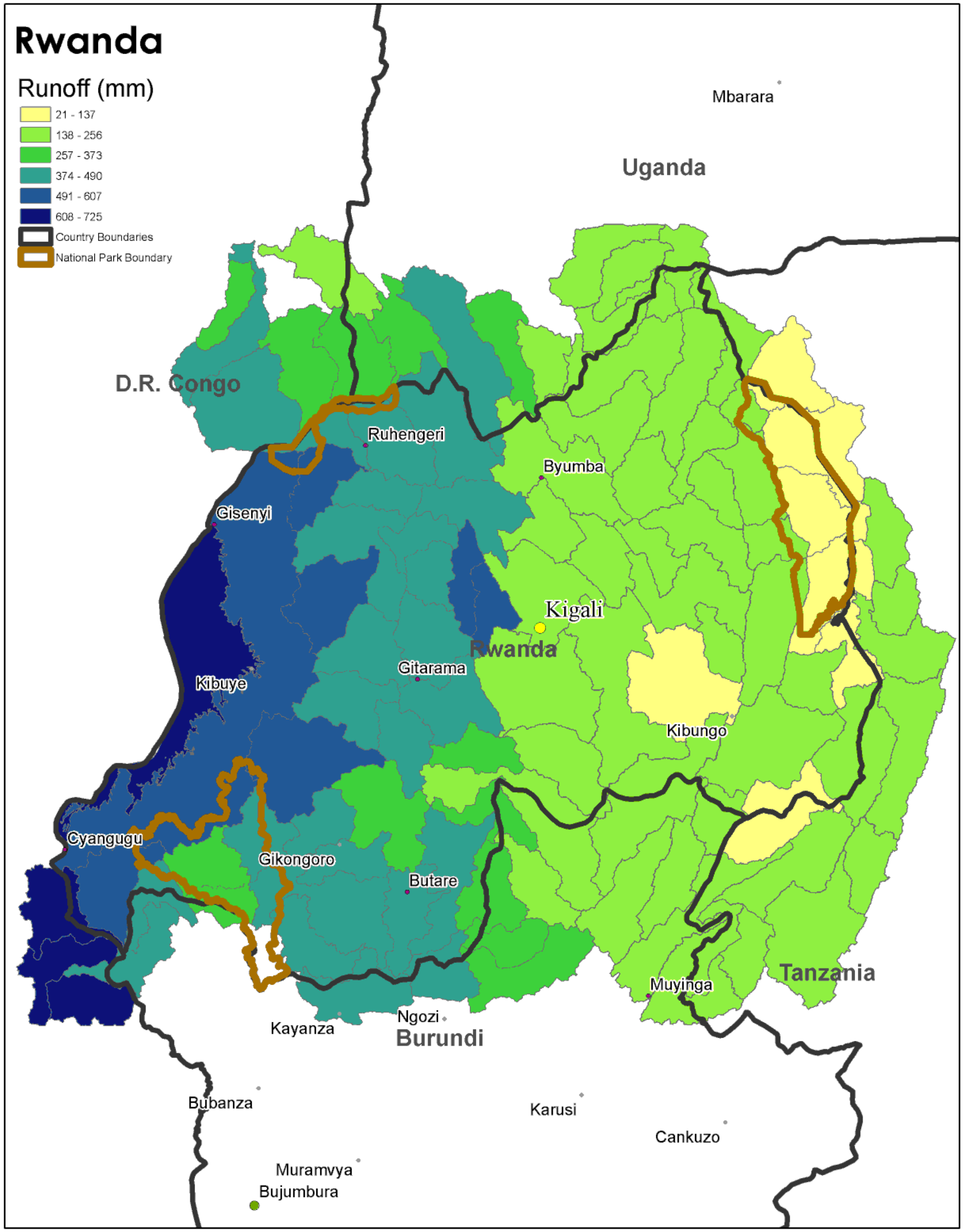
Model Application in Rwanda, Tanzania, Zambia

(Ge Sun)

Model Application in Rwanda Tanzania, and Zambia

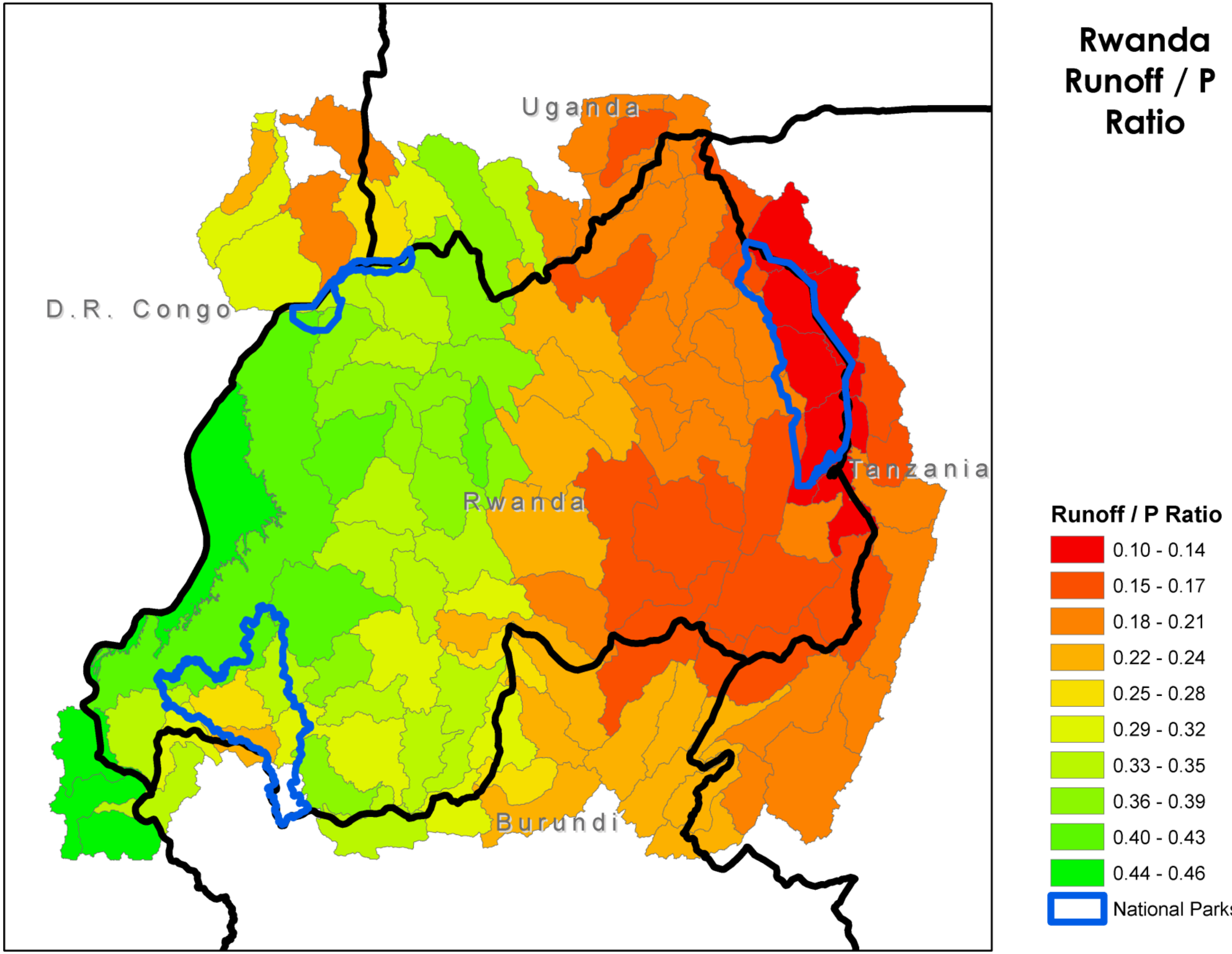
- Spatial scale: watershed
- Baseline
  - 1960-2009
- Future
  - 20% decrease in precipitation
  - 2 degree increase in temperature
  - 50% cut of forest
- Modeled Variables
  - Water Yield
  - Carbon sequestration (NEE, GEP)
  - Biodiversity

Baseline (1960-2009): Water Rwanda, Tanzania, and Zambia

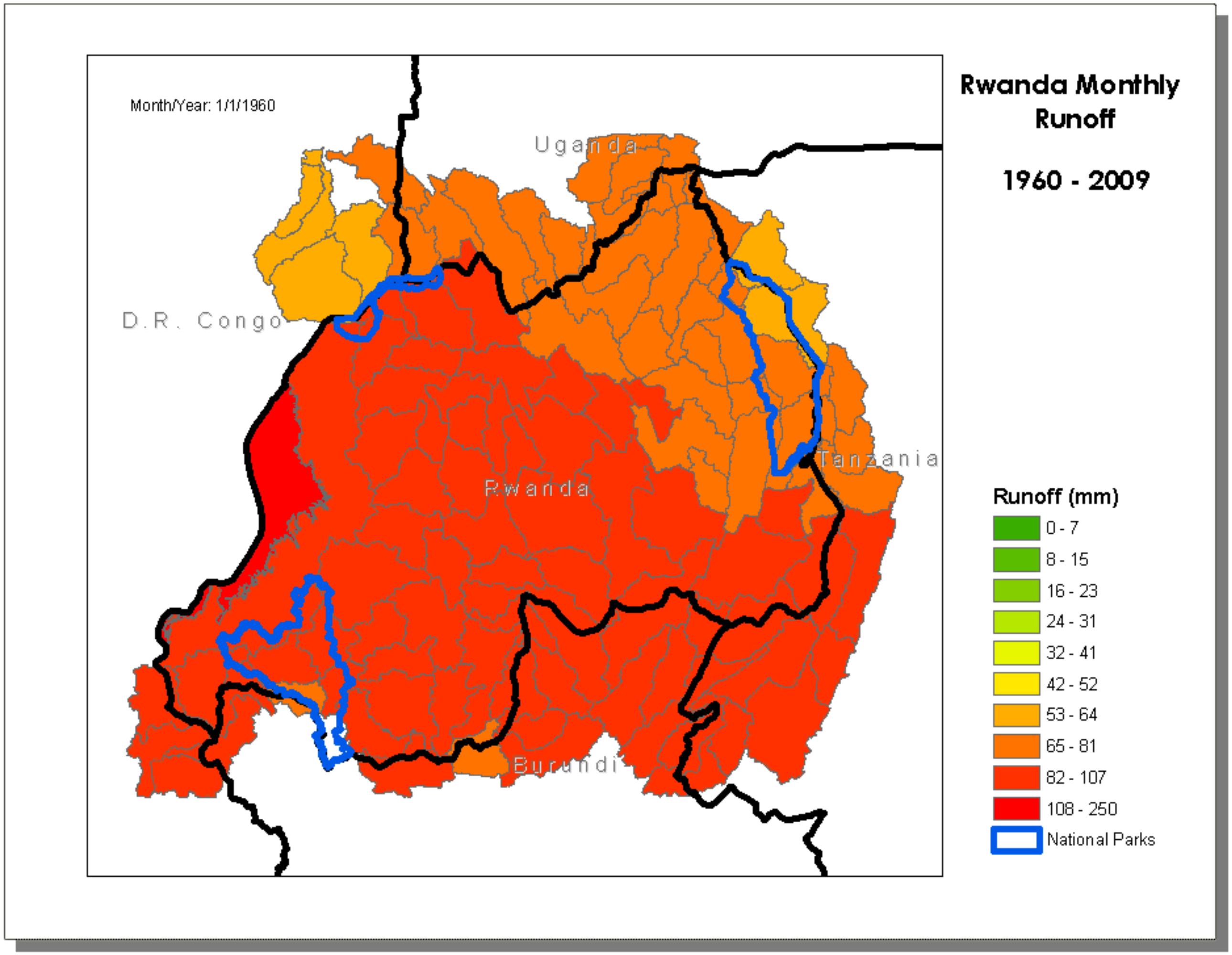


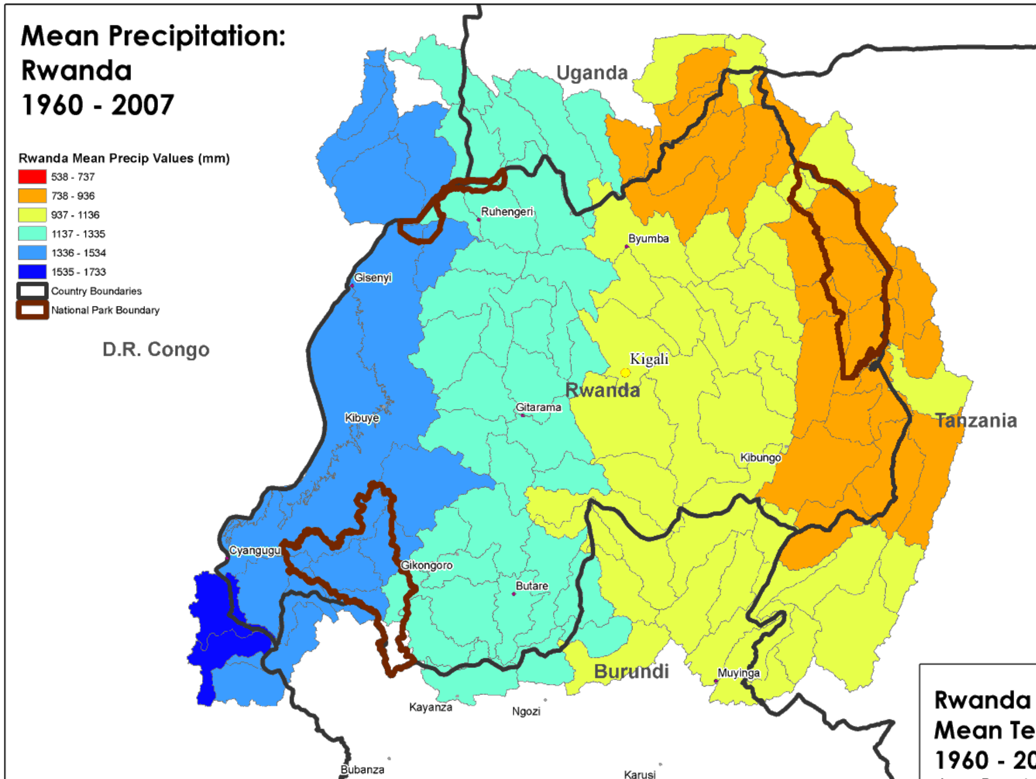
Rwanda
Runoff (mm)
21 - 137
138 - 256
257 - 373
374 - 490
491 - 607
608 - 725
Country Boundaries
National Park Boundary
Mbarara
Uganda
D.R. Congo
Ruhengeri
Byumba
Gisenyi
Kigali
Rwanda
Gitarama
Kibuye
Kibungo
Cyangugu
Gikongoro
Butare
Muyinga
Tanzania
Kayanza
Ngozi
Burundi
Bubanza
Karusi
Cankuzo
Muramvya
Bujumbura

Rwanda Runoff / P Ratio

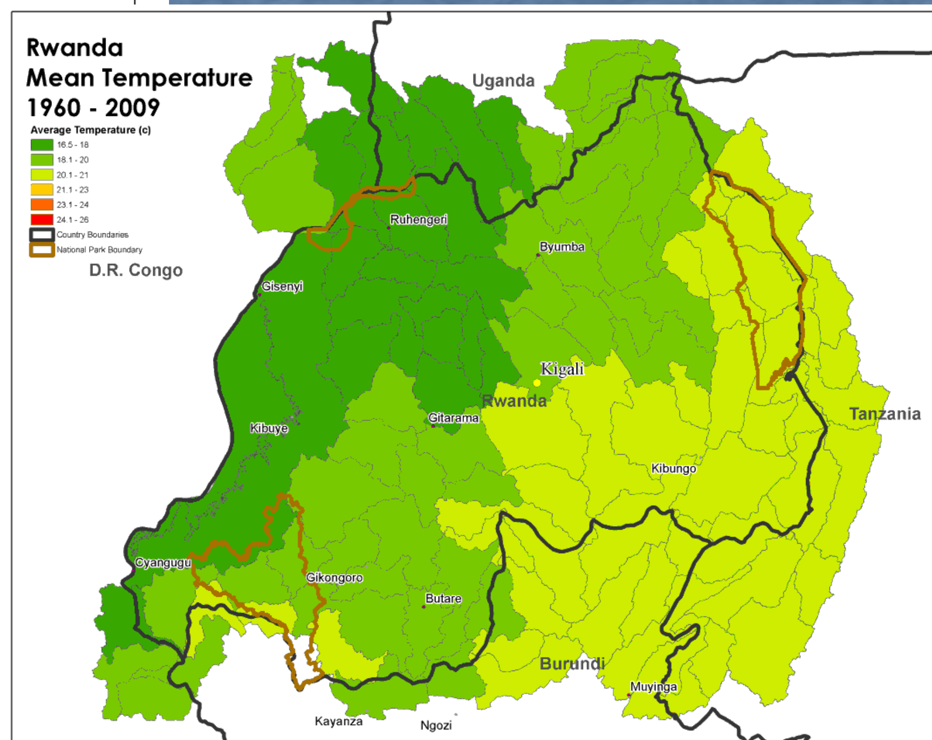


Monthly Runoff (1960-2009)



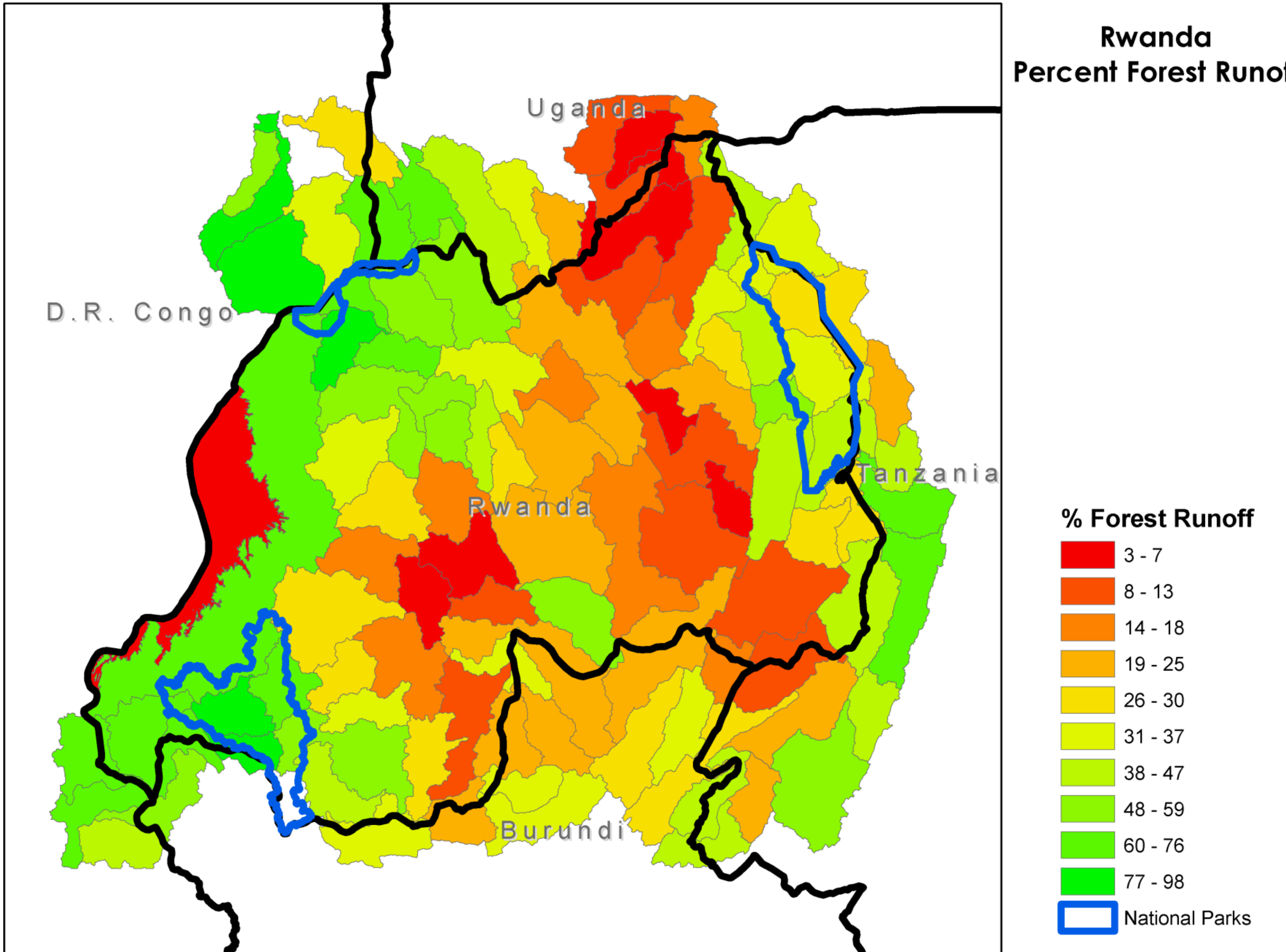


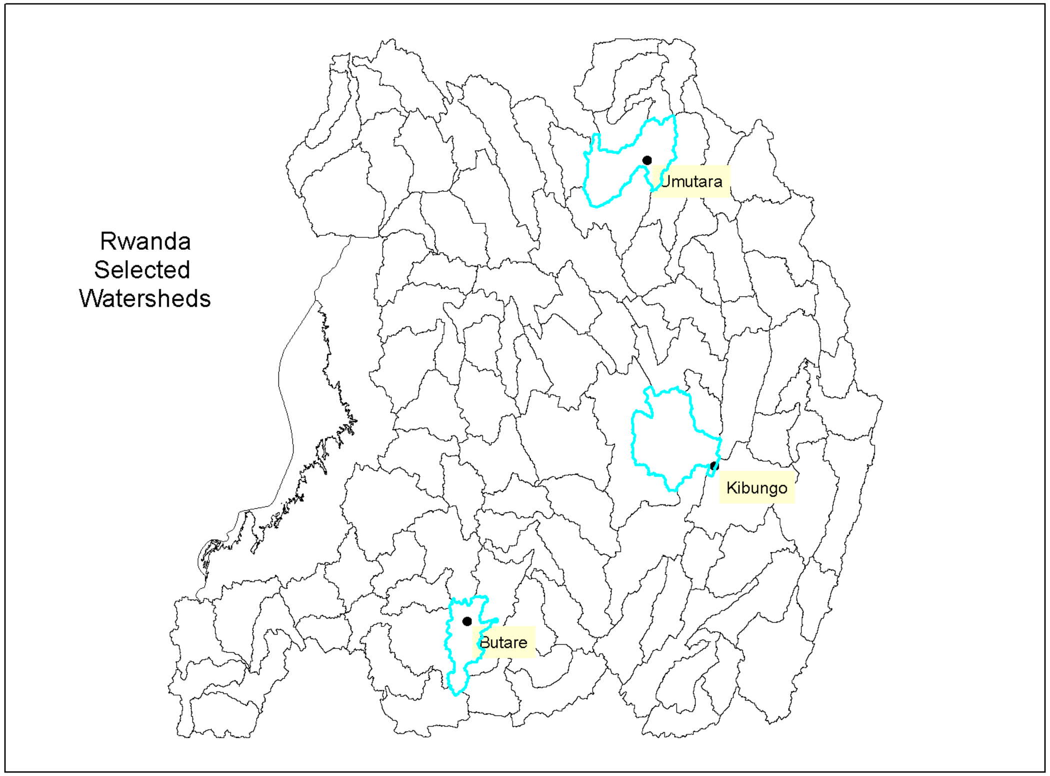
Mean Precipitation:
Rwanda
1960 - 2007
Rwanda Mean Precip Values (mm)
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1733
Country Boundaries
National Park Boundary
D.R. Congo
Uganda
Ruhengeri
Byumba
Gisenyi
Kigali
Rwanda
Gitarama
Kibuye
Kibungo
Tanzania
Cyangugu
Gikongoro
Butare
Burundi
Muyinga
Kayanza
Ngozi
Bubanza
Karusi

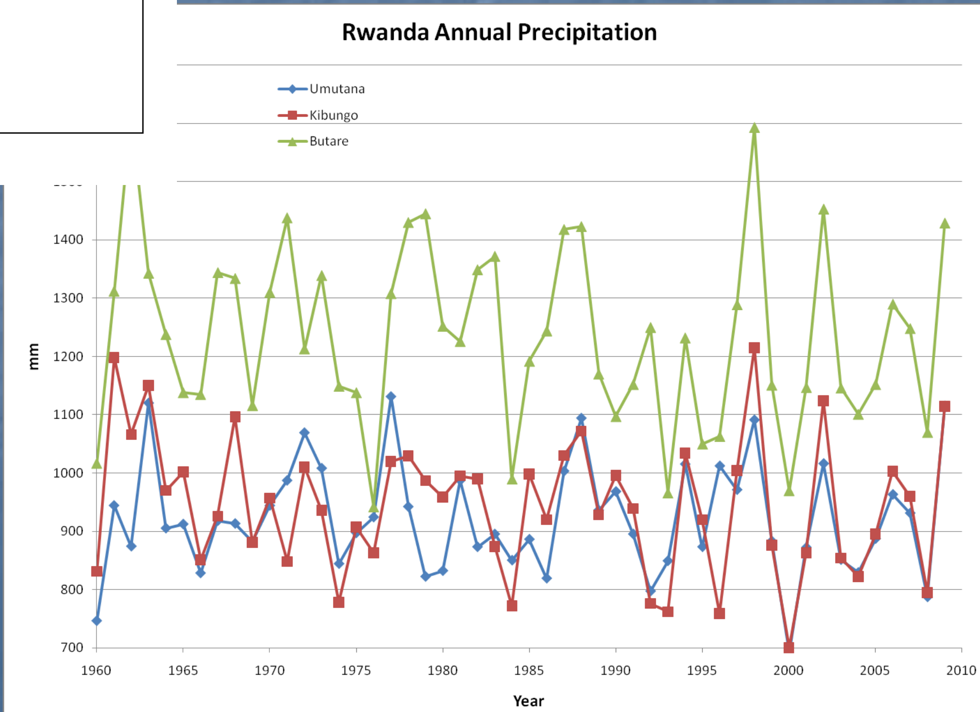


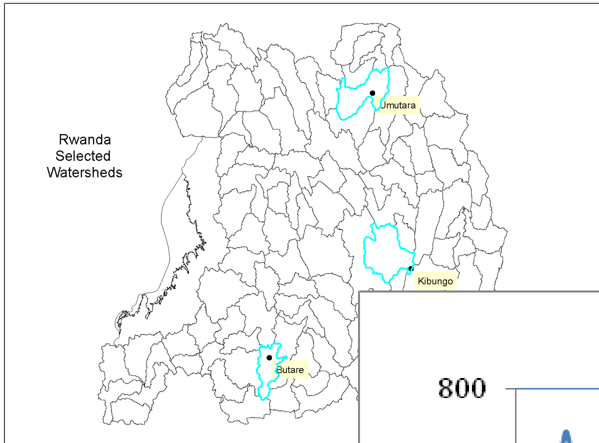
Rwanda
Mean Temperature
1960 - 2009
Average Temperature (c)
16.5 - 18
18.1 - 20
20.1 - 21
21.1 - 23
23.1 - 24
24.1 - 26
Country Boundaries
National Park Boundary
D.R. Congo
Uganda
Ruhengeri
Byumba
Gisenyi
Kigali
Rwanda
Gitarama
Kibuye
Kibungo
Tanzania
Cyangugu
Gikongoro
Butare
Burundi
Muyinga
Kayanza
Ngozi

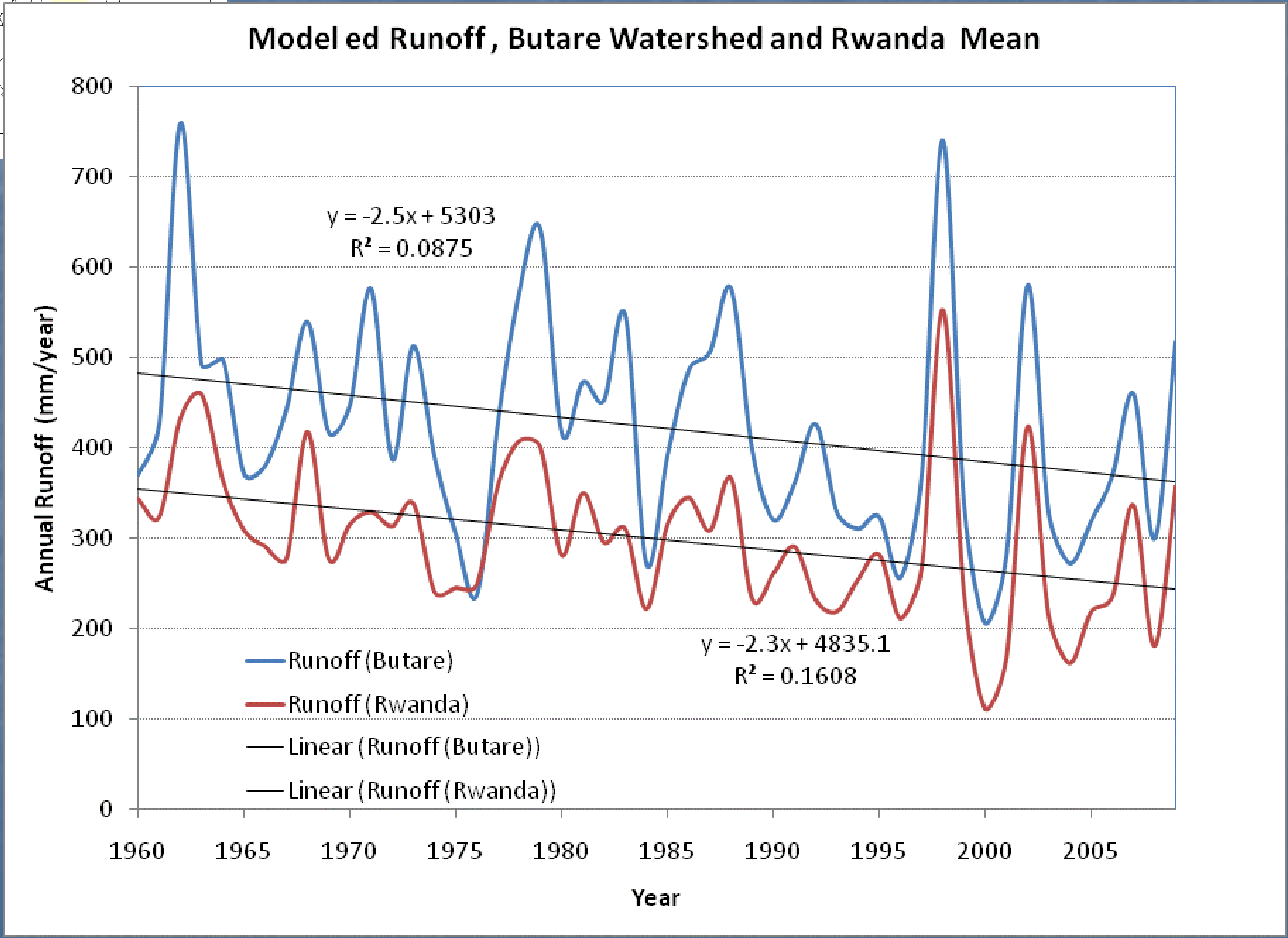
Rwanda
Percent Forest Runoff

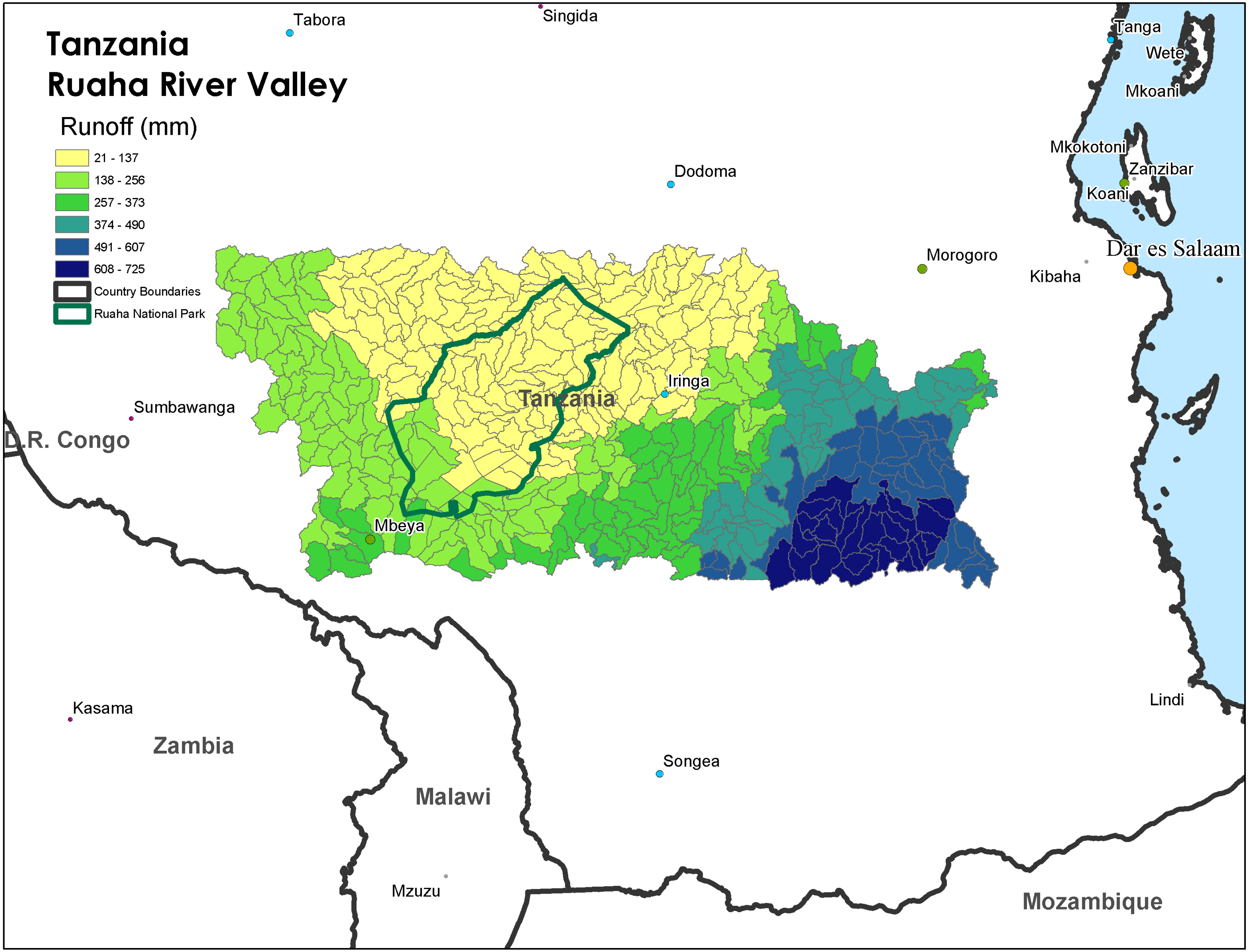


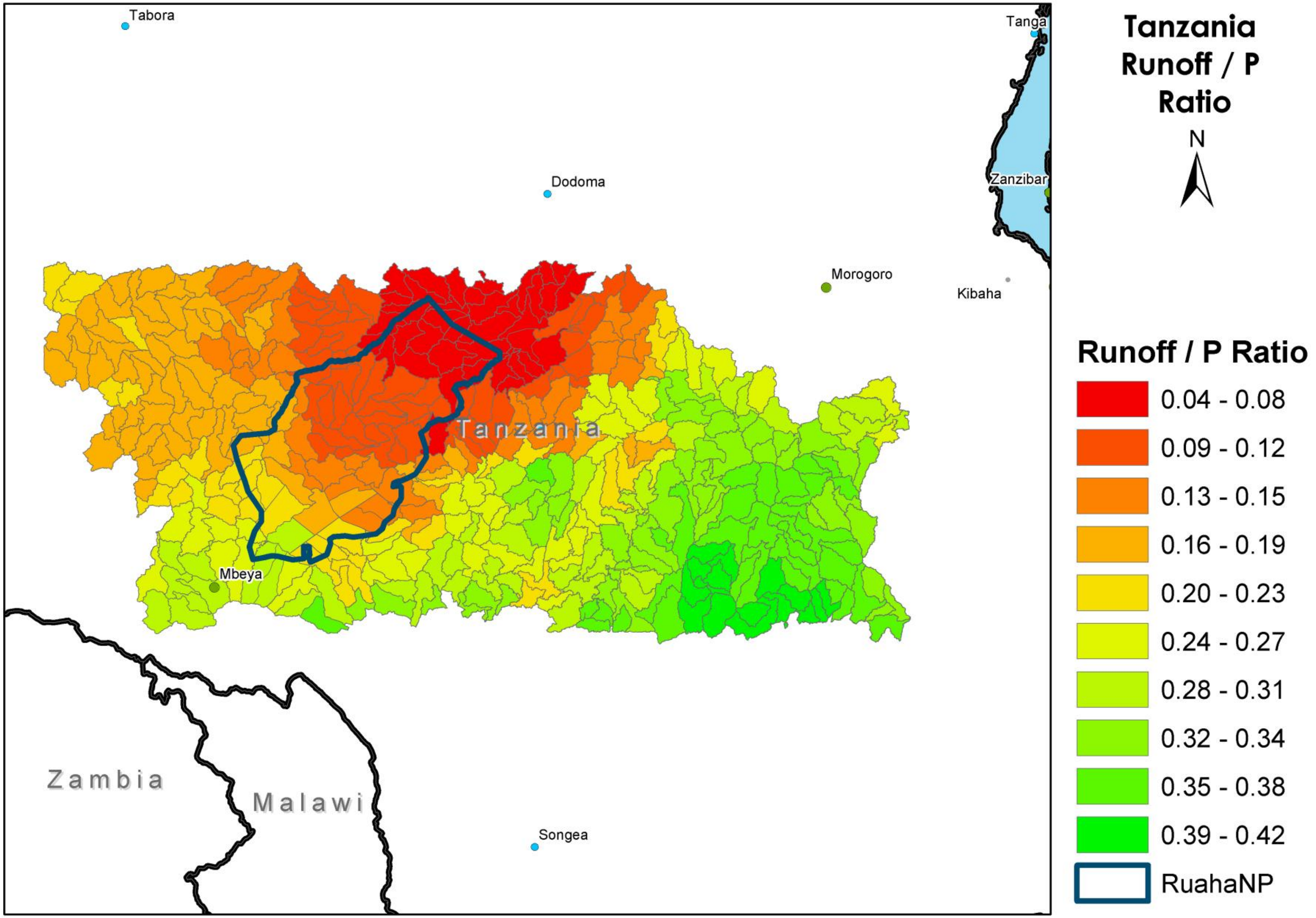

Rwanda
Selected
Watersheds
Umutara
Kibungo
Butare

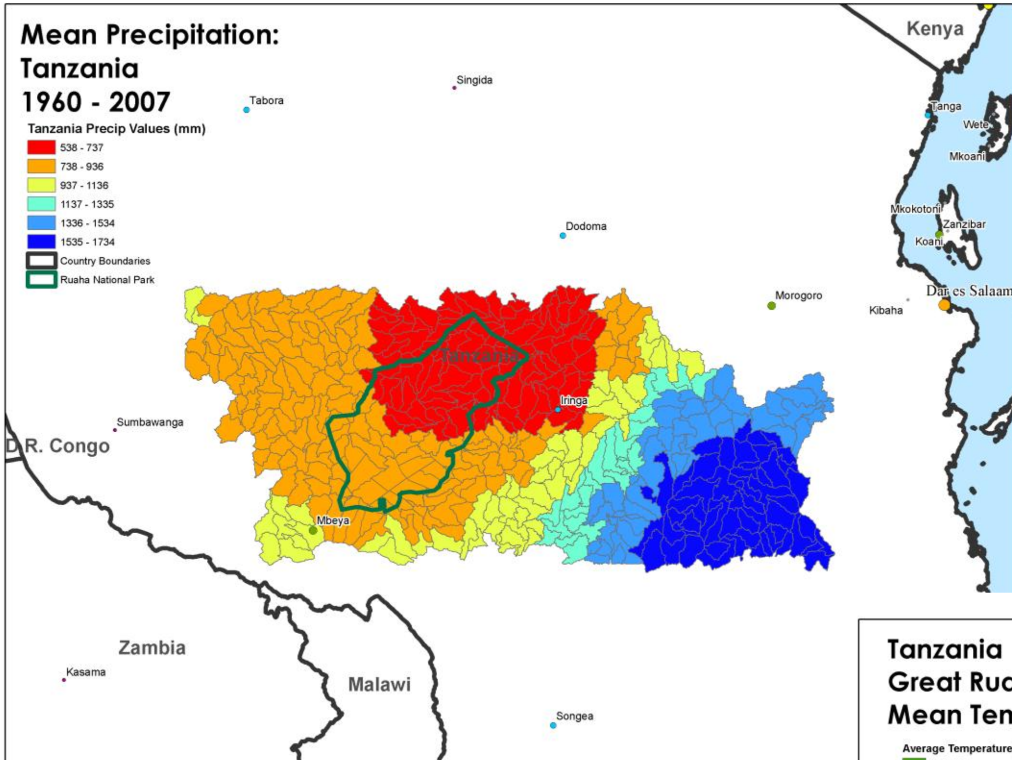

Rwanda Annual Precipitation
Umutana
Kibungo
Butare
mm
1400
1300
1200
1100
1000
900
800
700
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

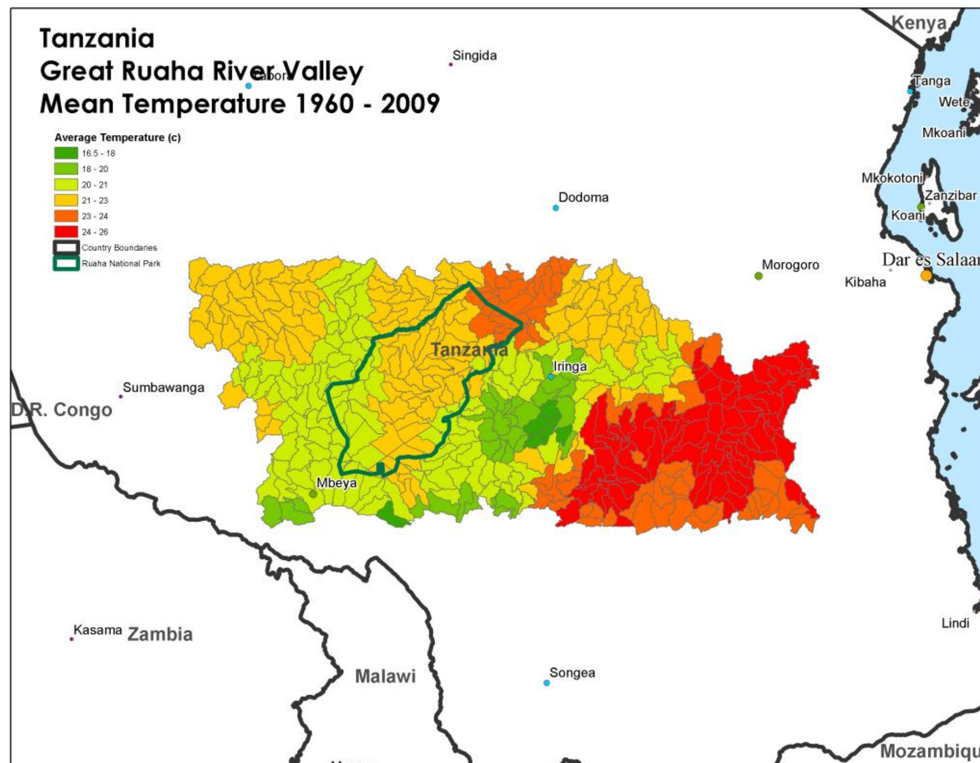

Rwanda
Selected
Watersheds
Umutara
Kibungo
Butare


Model ed Runoff , Butare Watershed and Rwanda Mean
y = -2.5x + 5303
R² = 0.0875
y = -2.3x + 4835.1
R² = 0.1608
Runoff (Butare)
Runoff (Rwanda)
Linear (Runoff (Butare))
Linear (Runoff (Rwanda))
Annual Runoff (mm/year)
Year
0
100
200
300
400
500
600
700
800
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

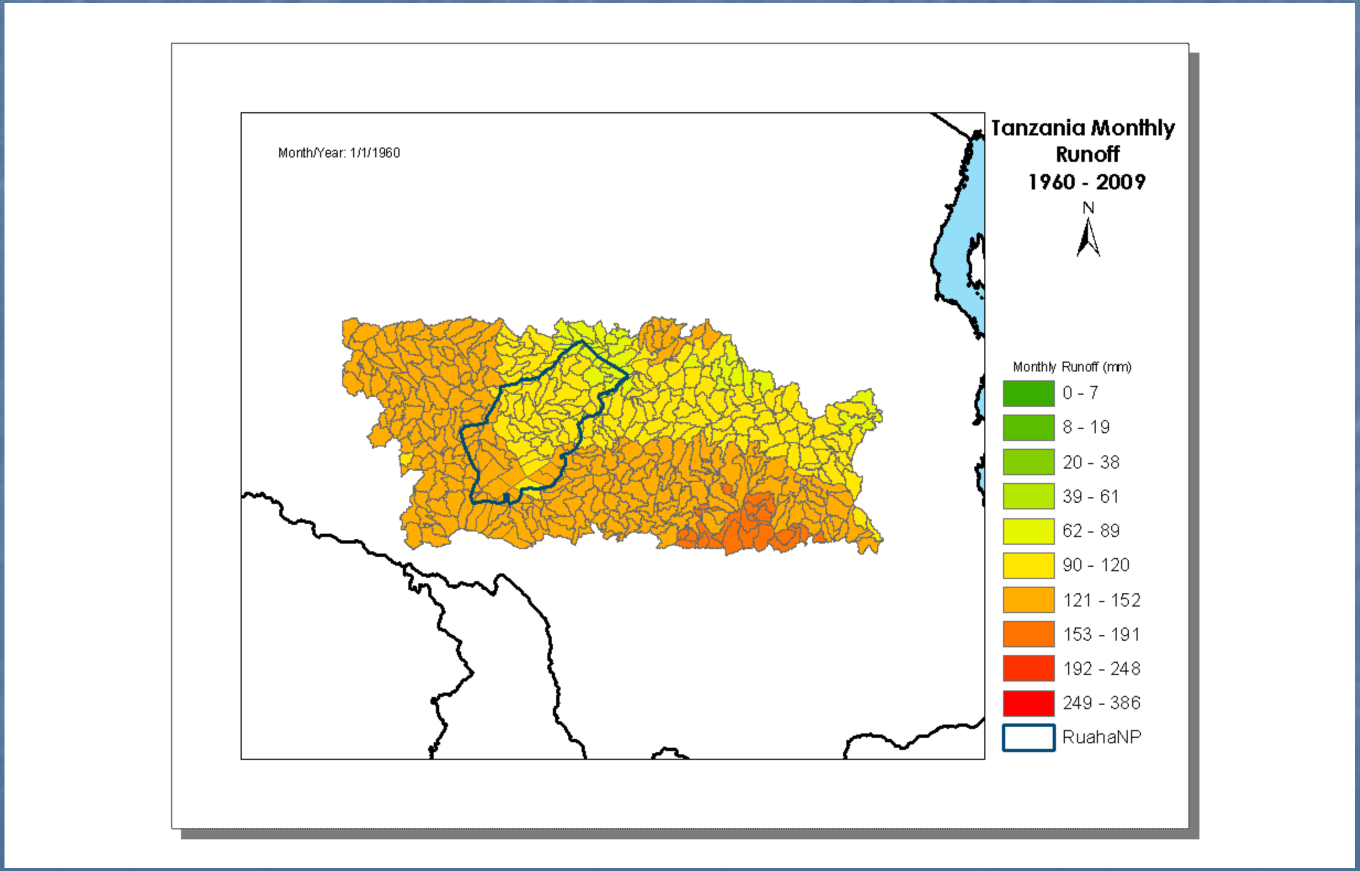

Tanzania
Ruaha River Valley
Runoff (mm)
21 - 137
138 - 256
257 - 373
374 - 490
491 - 607
608 - 725
Country Boundaries
Ruaha National Park
Tabora
Singida
Tanga
Wete
Mkoani
Mkokotoni
Zanzibar
Koani
Dodoma
Morogoro
Kibaha
Dar es Salaam
Iringa
Tanzania
Sumbawanga
D.R. Congo
Mbeya
Kasama
Zambia
Songea
Lindi
Malawi
Mzuzu
Mozambique

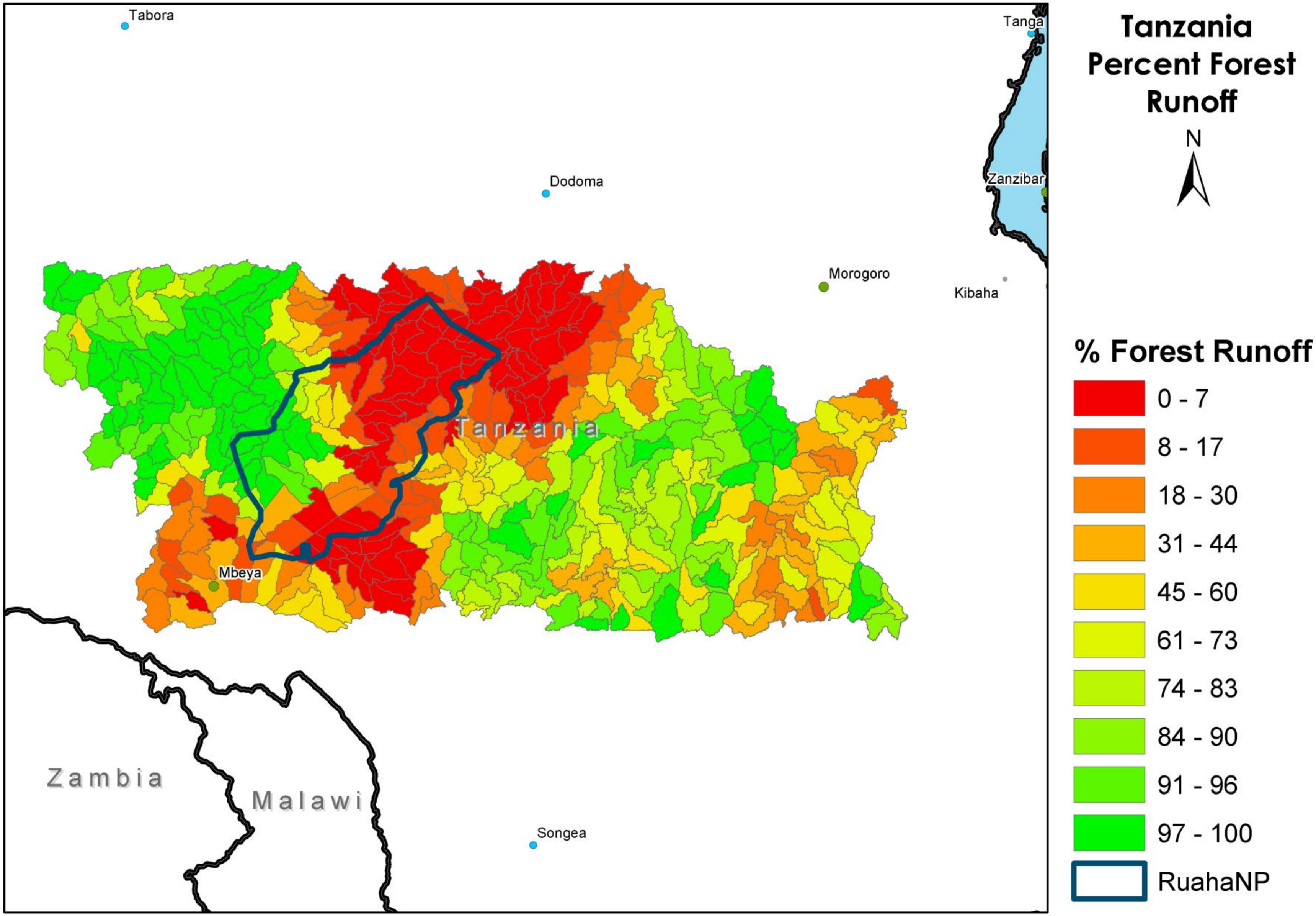

Tanzania
Runoff / P
Ratio
N
Tabora
Tanga
Dodoma
Zanzibar
Morogoro
Kibaha
Tanzania
Mbeya
Zambia
Malawi
Songea
Runoff / P Ratio
0.04 - 0.08
0.09 - 0.12
0.13 - 0.15
0.16 - 0.19
0.20 - 0.23
0.24 - 0.27
0.28 - 0.31
0.32 - 0.34
0.35 - 0.38
0.39 - 0.42
RuahaNP


Mean Precipitation:
Tanzania
1960 - 2007
Tanzania Precip Values (mm)
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1734
Country Boundaries
Ruaha National Park
Kenya
Singida
Tabora
Tanga
Wete
Mkoani
Mkokotoni
Zanzibar
Koani
Dodoma
Dar es Salaam
Morogoro
Kibaha
Iringa
Sumbawanga
D.R. Congo
Mbeya
Zambia
Kasama
Malawi
Songea

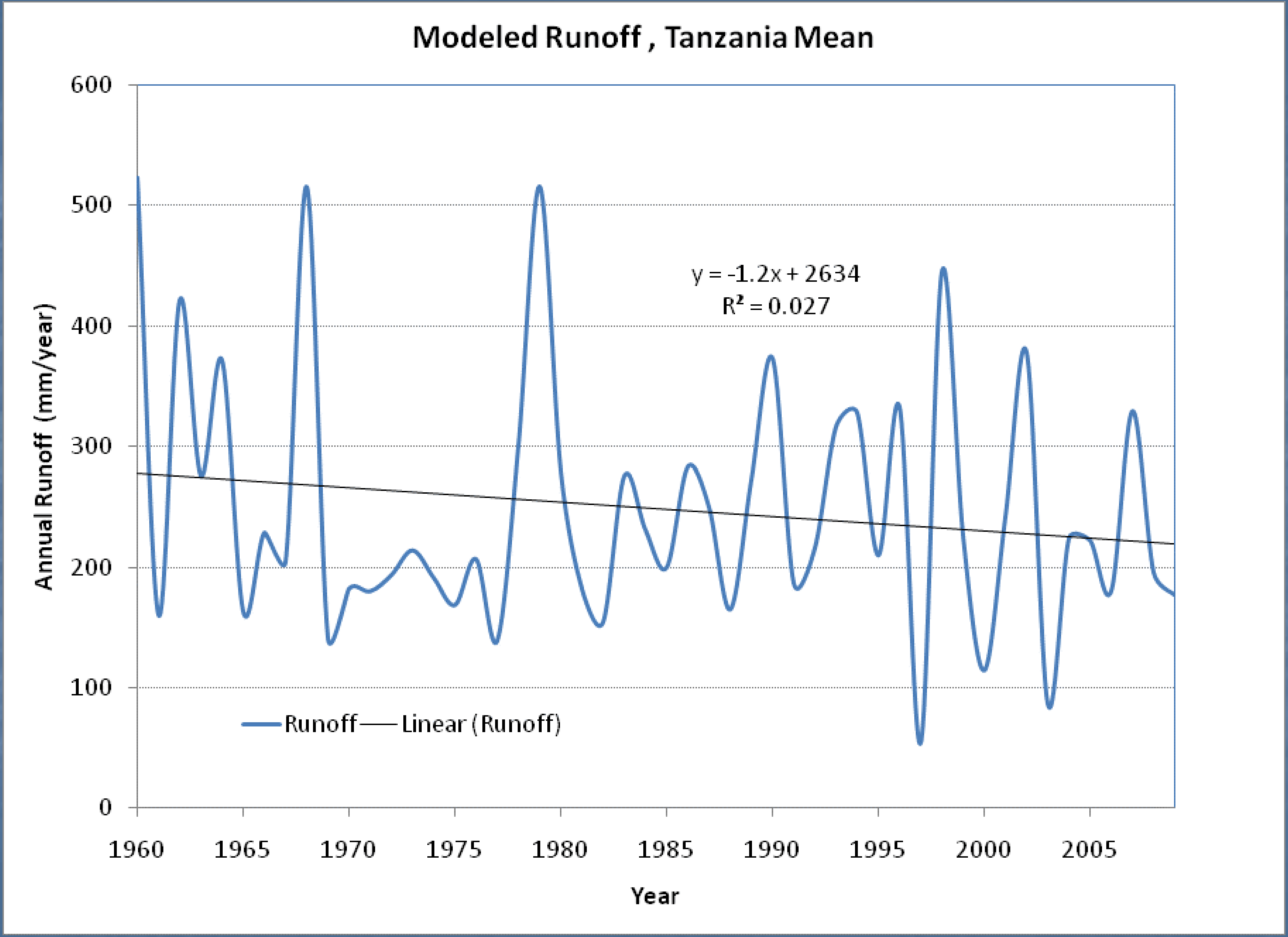

Tanzania
Great Ruaha River Valley
Mean Temperature 1960 - 2009
Average Temperature (c)
16.5 - 18
18 - 20
20 - 21
21 - 23
23 - 24
24 - 26
Country Boundaries
Ruaha National Park
Kenya
Singida
Tanga
Wete
Mkoani
Mkokotoni
Zanzibar
Koani
Dodoma
Dar es Salaam
Morogoro
Kibaha
Tanzania
Iringa
Sumbawanga
D.R. Congo
Mbeya
Kasama
Zambia
Malawi
Songea
Lindi
Mozambique
Mzuzu

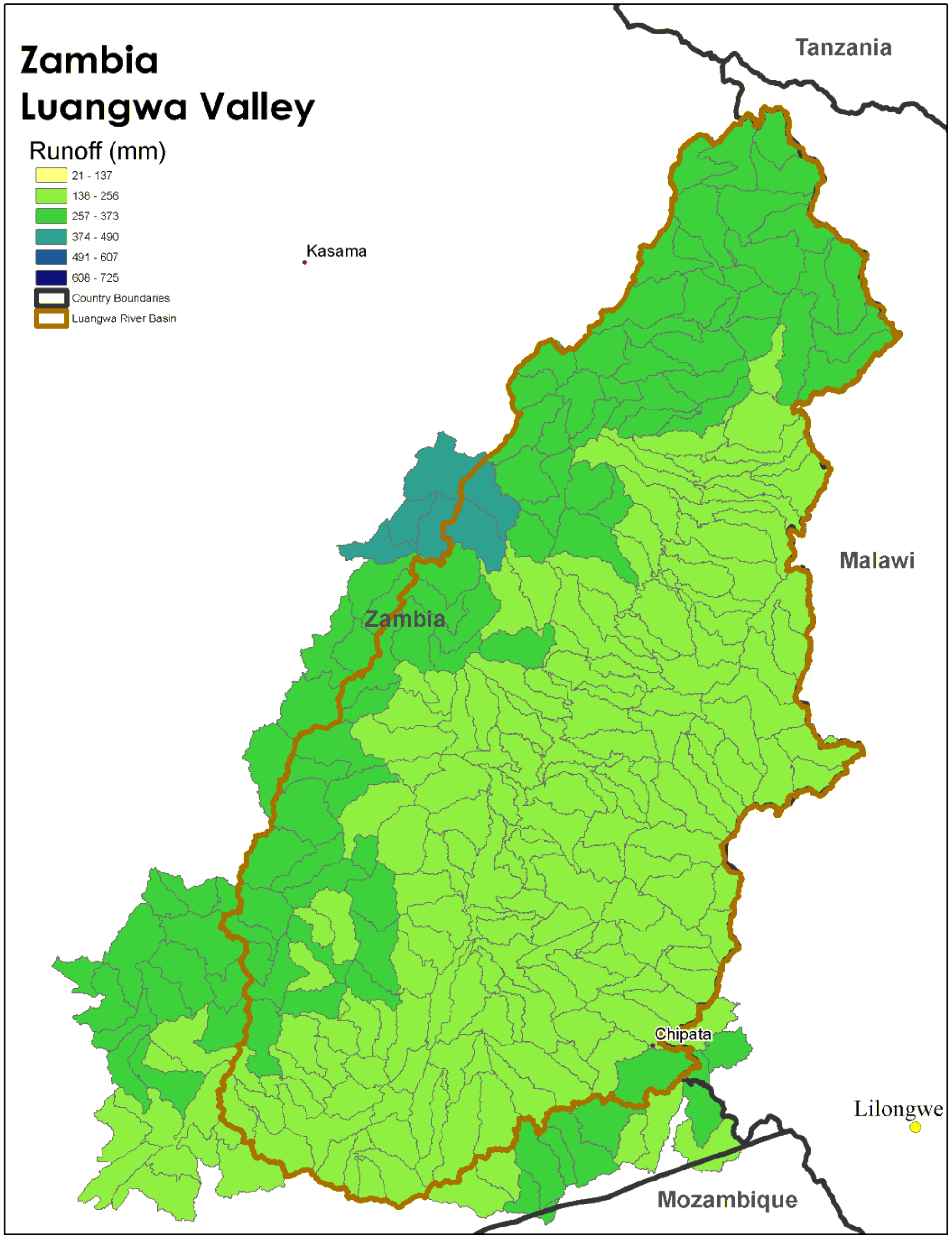
Monthly Runoff (1960-2009)



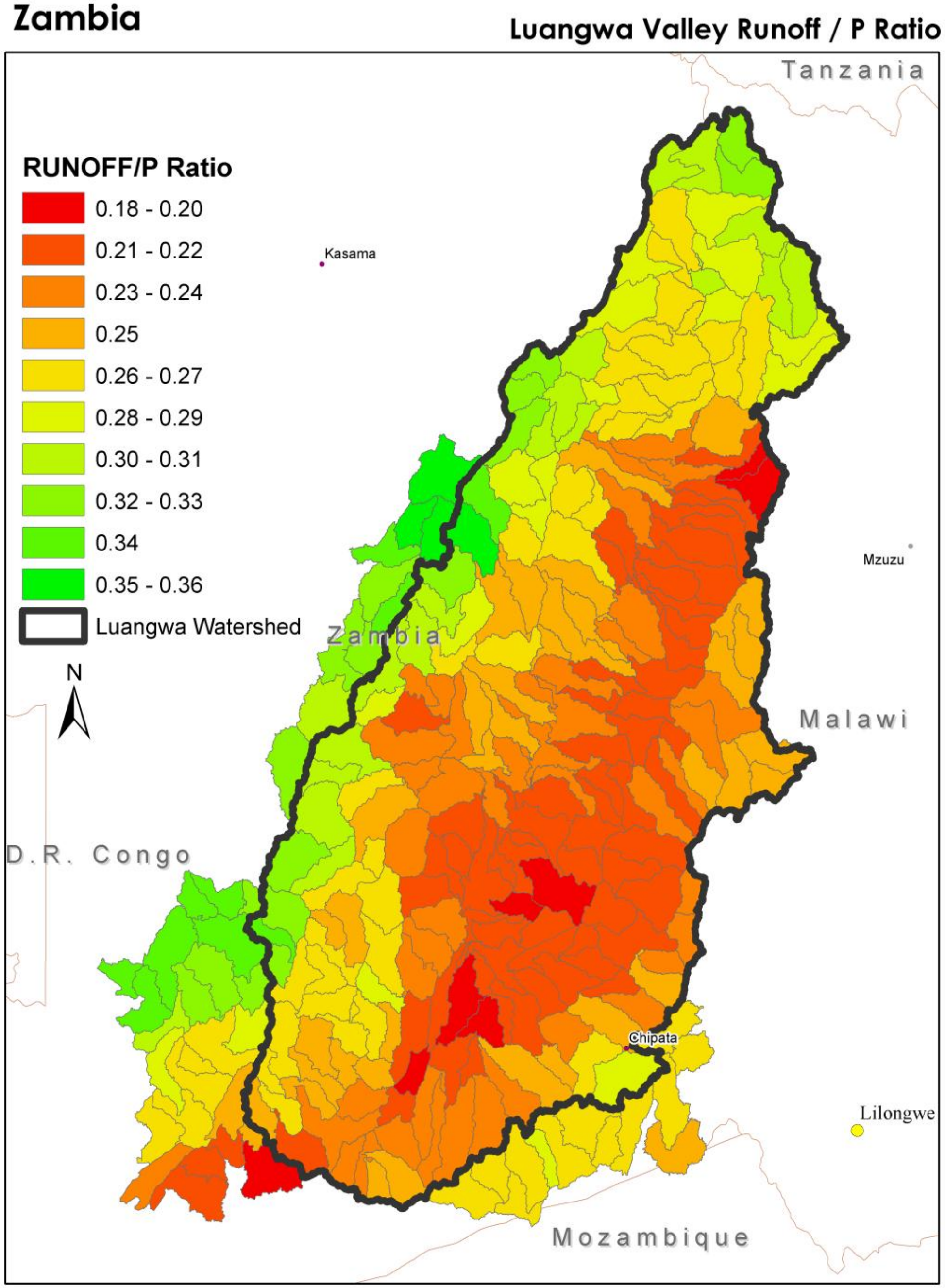


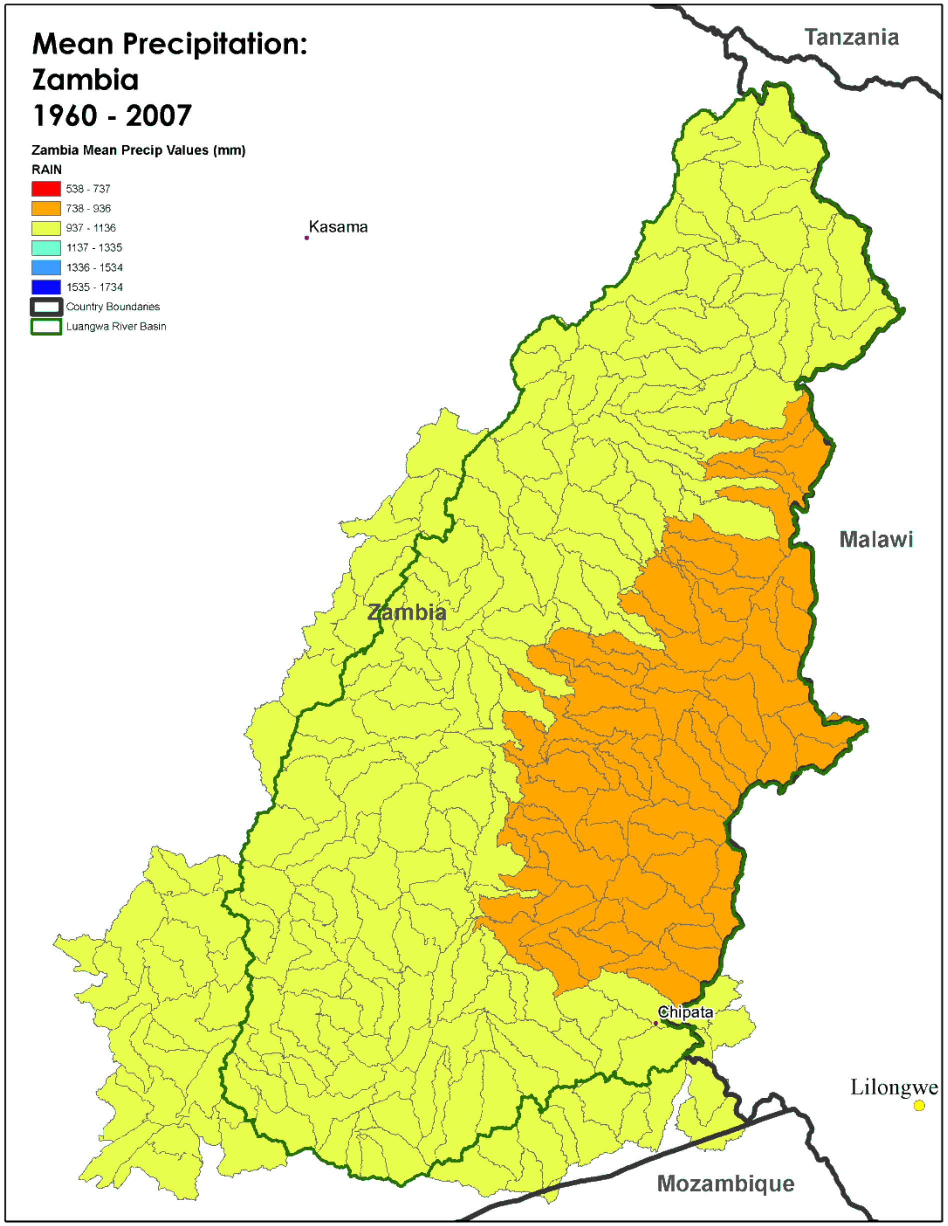
Tabora
Tanga
Dodoma
Zanzibar
Morogoro
Kibaha
Tanzania
Mbeya
Zambia
Malawi
Songea
Tanzania
Percent Forest
Runoff
N
% Forest Runoff
0 - 7
8 - 17
18 - 30
31 - 44
45 - 60
61 - 73
74 - 83
84 - 90
91 - 96
97 - 100
RuahaNP


Modeled Runoff , Tanzania Mean
Annual Runoff (mm/year)
600
500
400
300
200
100
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
y = -1.2x + 2634
R² = 0.027
Runoff
Linear (Runoff)

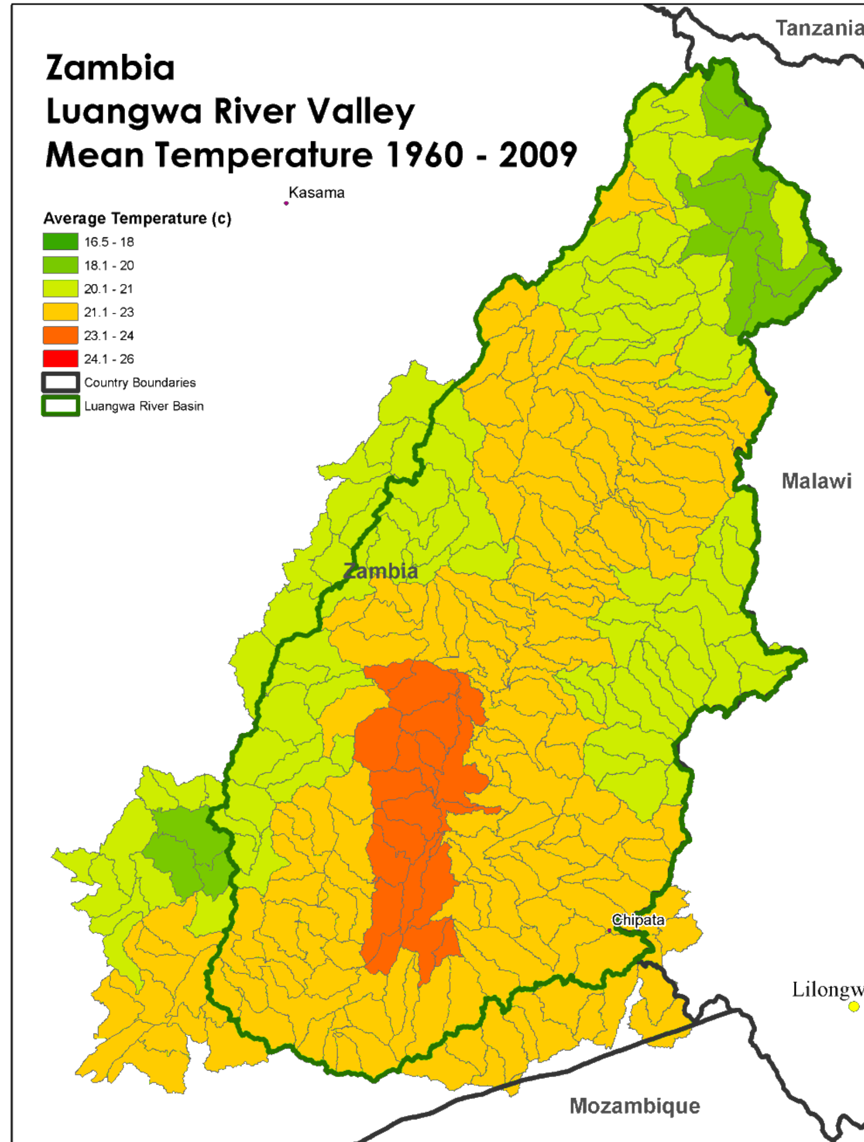

Zambia
Luangwa Valley
Runoff (mm)
21 - 137
138 - 256
257 - 373
374 - 490
491 - 607
608 - 725
Country Boundaries
Luangwa River Basin
Tanzania
Kasama
Malawi
Zambia
Chipata
Lilongwe
Mozambique

Zambia


Luangwa Valley Runoff / P Ratio
RUNOFF/P Ratio
0.18 - 0.20
0.21 - 0.22
0.23 - 0.24
0.25
0.26 - 0.27
0.28 - 0.29
0.30 - 0.31
0.32 - 0.33
0.34
0.35 - 0.36
Luangwa Watershed
N
Tanzania
Kasama
Mzuzu
Zambia
Malawi
D.R. Congo
Chipata
Lilongwe
Mozambique

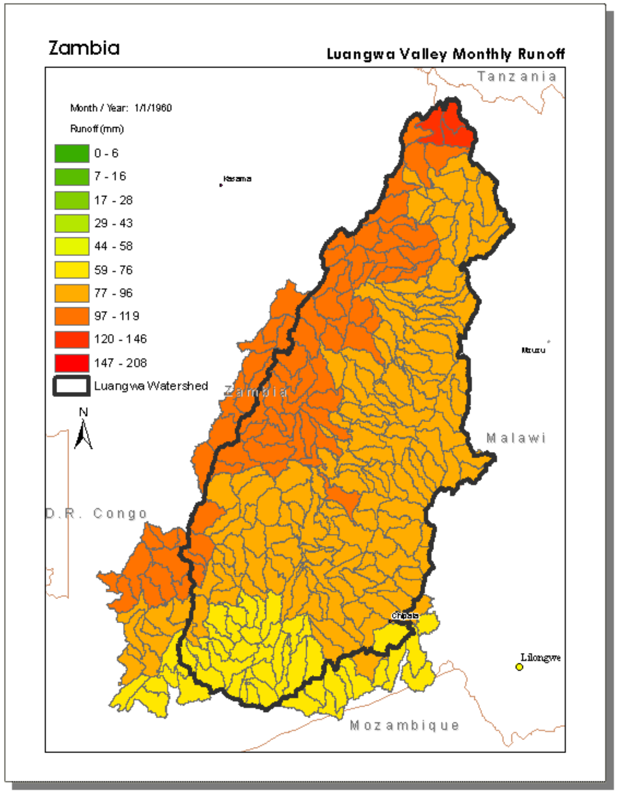


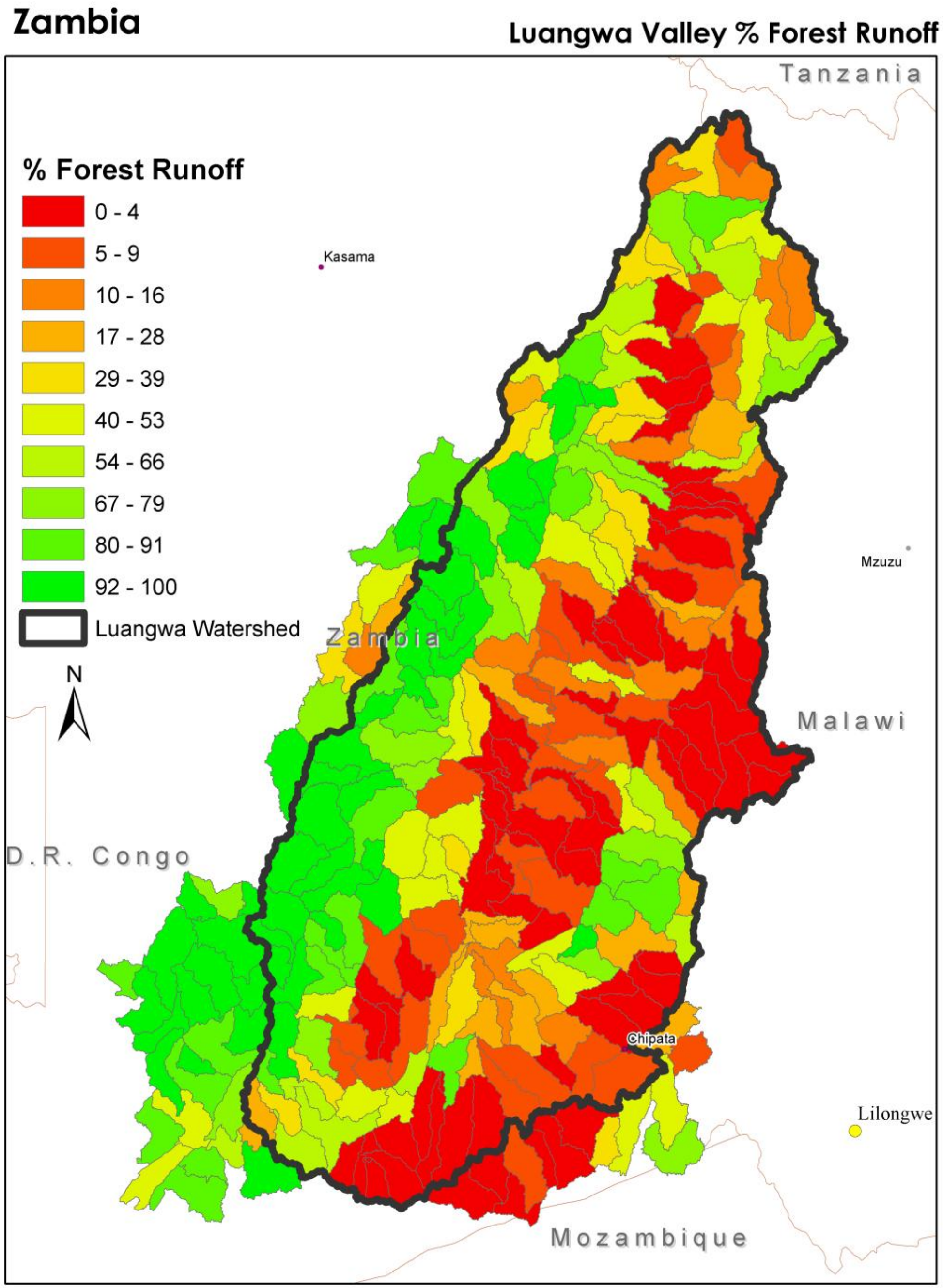
Mean Precipitation:
Zambia
1960 - 2007
Zambia Mean Precip Values (mm)
RAIN
538 - 737
738 - 936
937 - 1136
1137 - 1335
1336 - 1534
1535 - 1734
Country Boundaries
Luangwa River Basin
Tanzania
Kasama
Malawi
Zambia
Chipata
Lilongwe
Mozambique

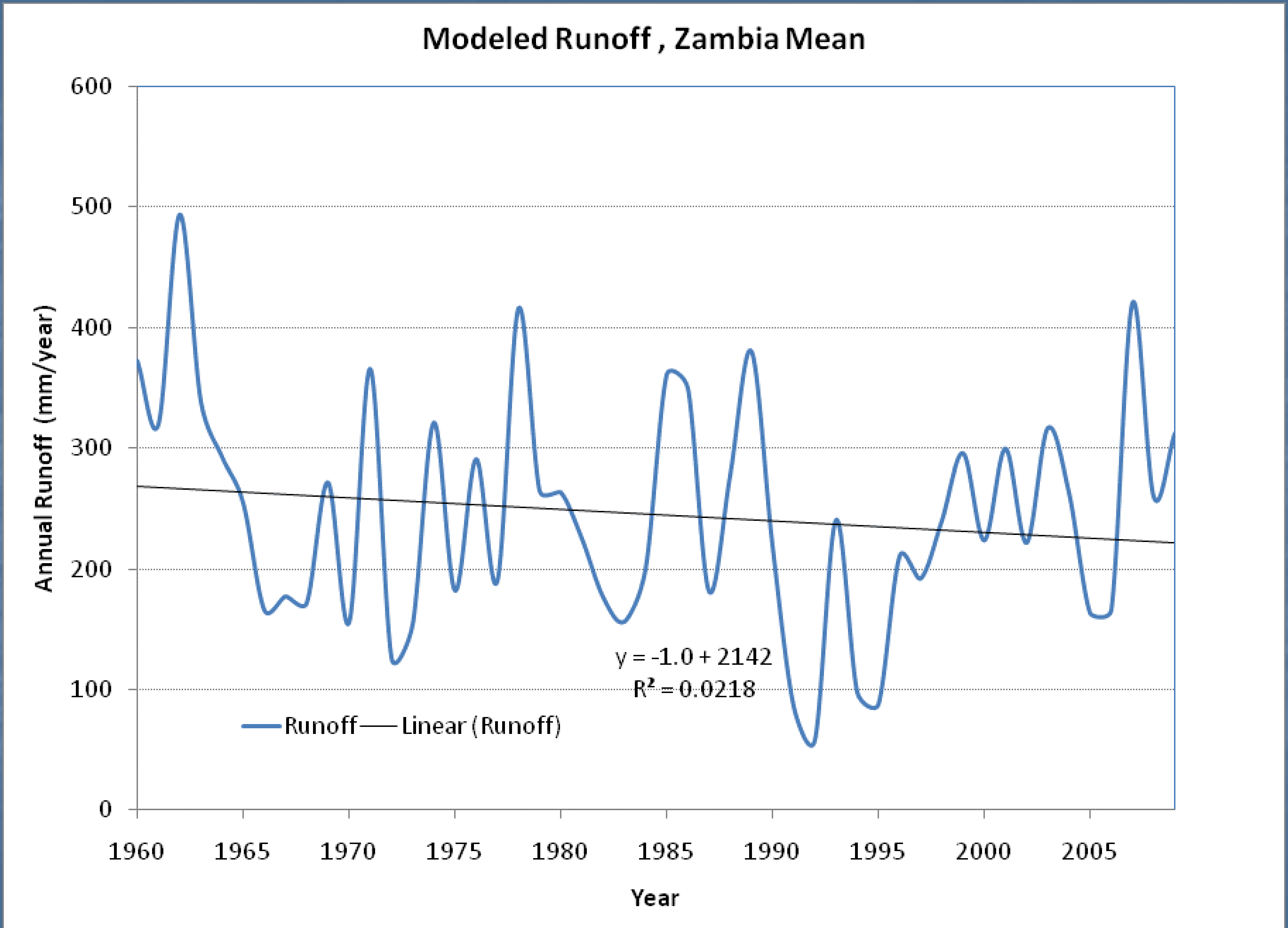


Zambia
Luangwa River Valley
Mean Temperature 1960 - 2009
Average Temperature (c)
16.5 - 18
18.1 - 20
20.1 - 21
21.1 - 23
23.1 - 24
24.1 - 26
Country Boundaries
Luangwa River Basin
Tanzania
Kasama
Malawi
Zambia
Chipata
Lilongwe
Mozambique

Monthly Runoff (1960-2009)




Zambia
Luangwa Valley % Forest Runoff
% Forest Runoff
0 - 4
5 - 9
10 - 16
17 - 28
29 - 39
40 - 53
54 - 66
67 - 79
80 - 91
92 - 100
Luangwa Watershed
N
Tanzania
Kasama
Mzuzu
Zambia
Malawi
D.R. Congo
Chipata
Lilongwe
Mozambique



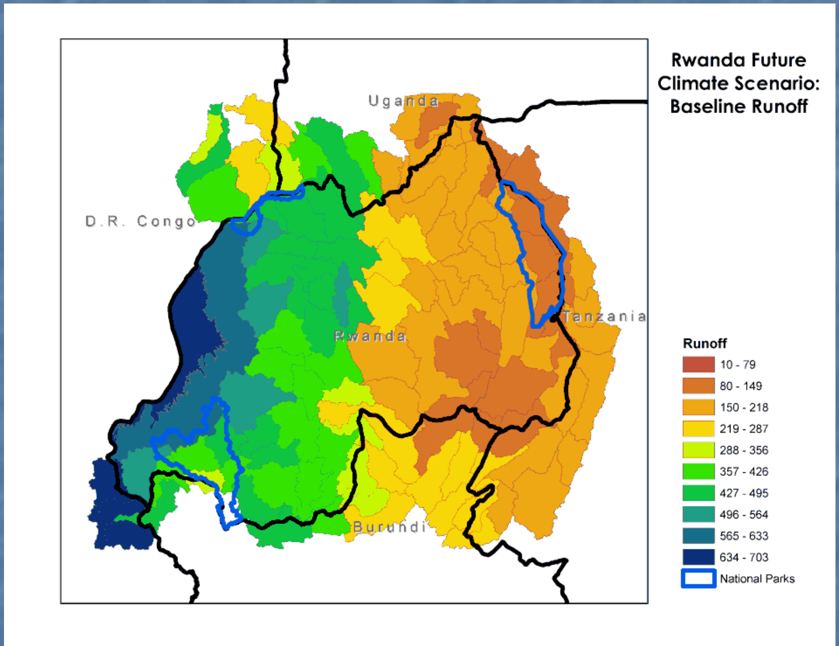
Modeled Runoff , Zambia Mean
600
500
400
300
200
100
0
Annual Runoff (mm/year)
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
y = -1.0 + 2142
R² = 0.0218
Runoff
Linear (Runoff)

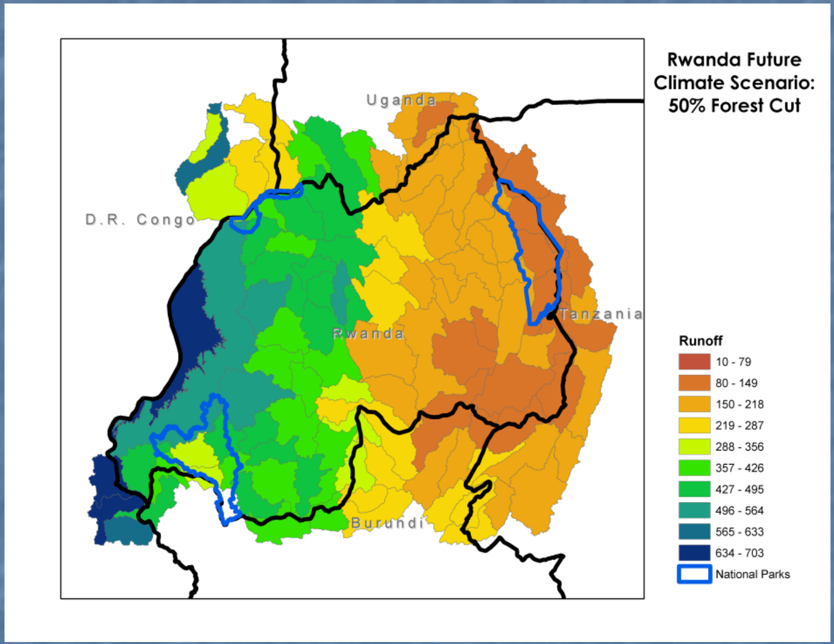
Potential Hydrologic Impacts of Landcover Change and Climate Change (Rwanda)

Three Scenarios

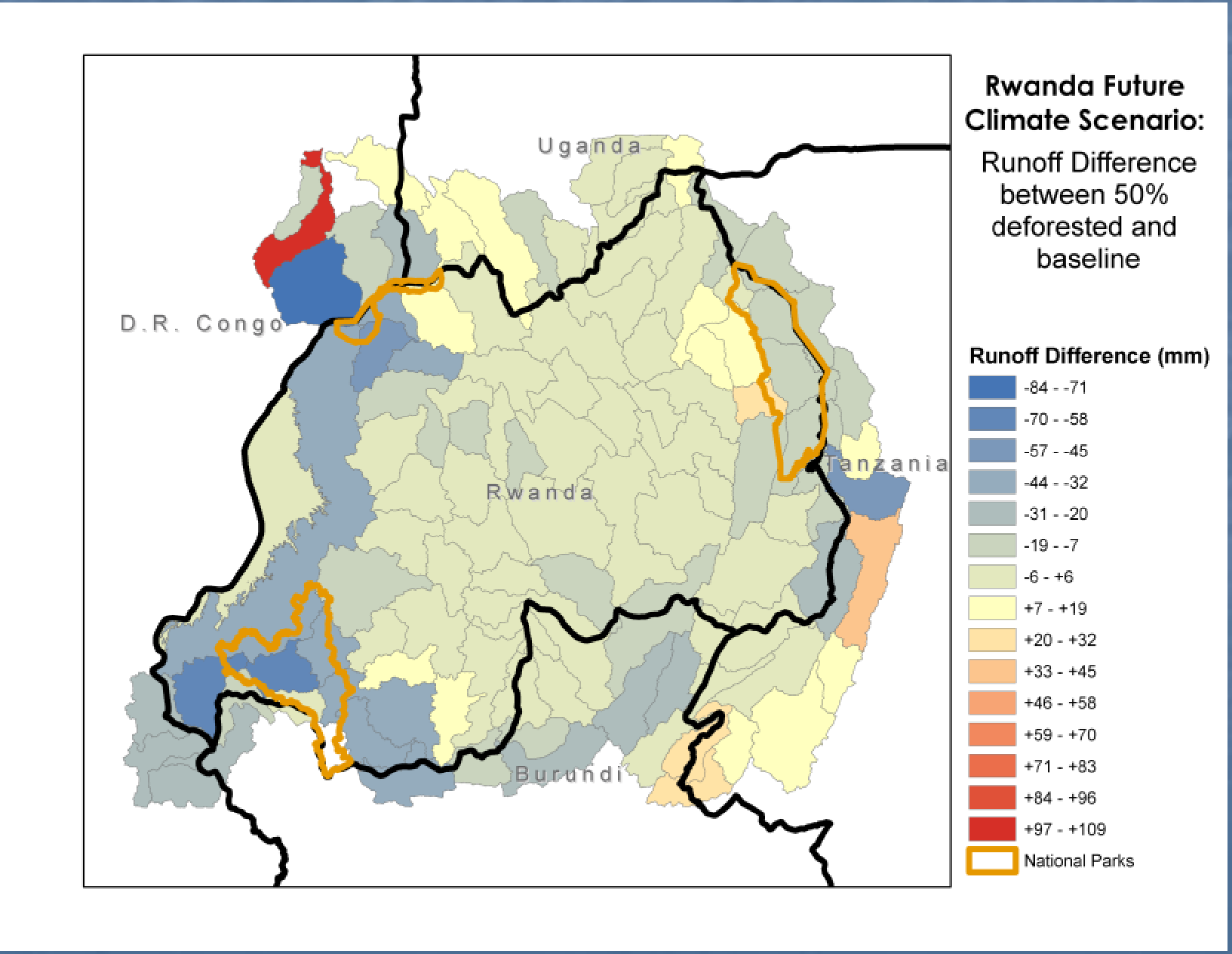
- 50% Deforestation
- Temp increase 2 Degree C
- Temp increase 2 Degree C + 20% Precip Reduction

50% Deforestation

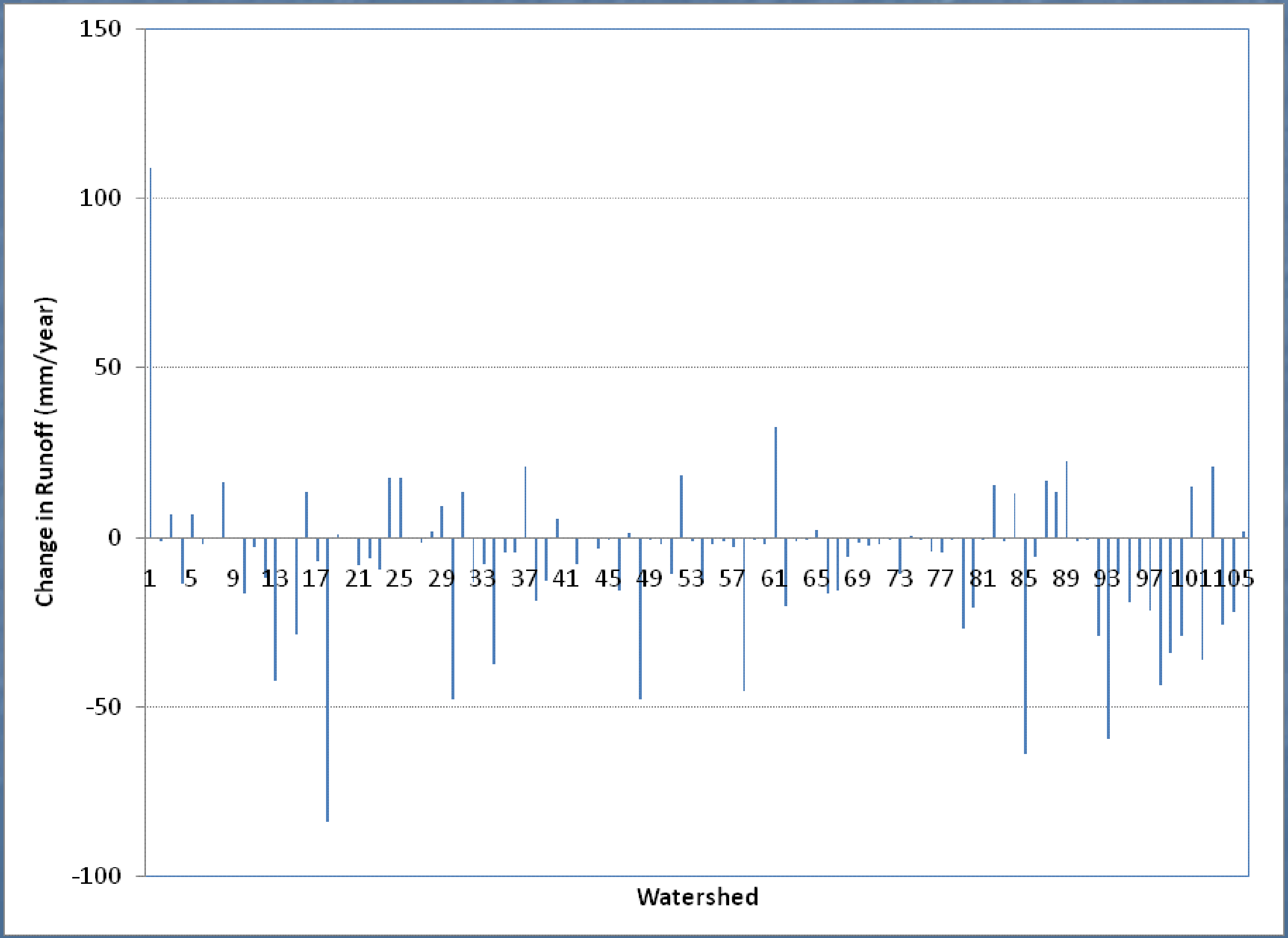




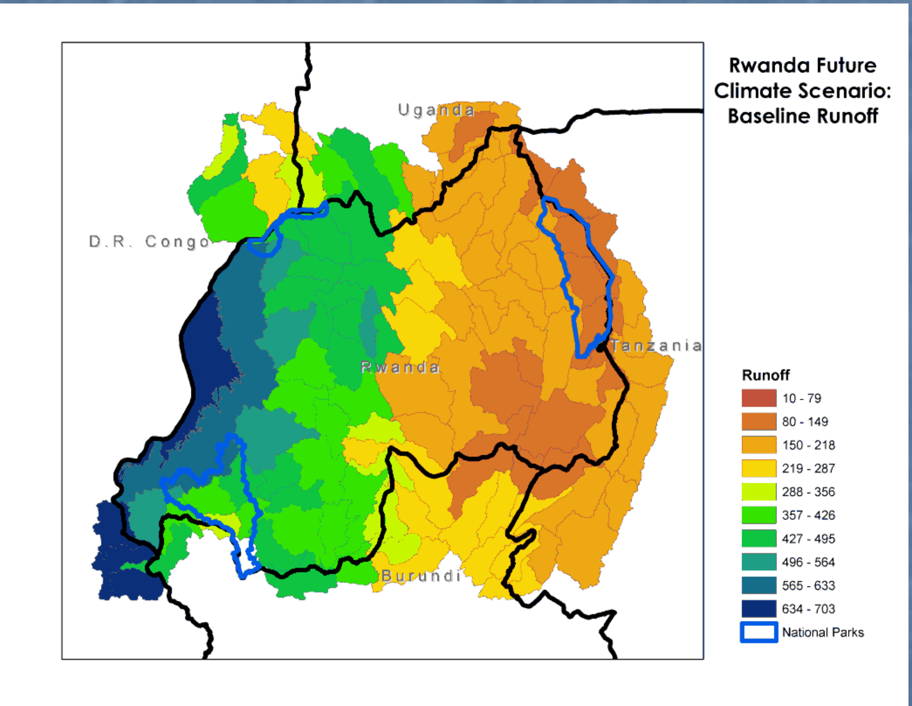
50% Deforestation

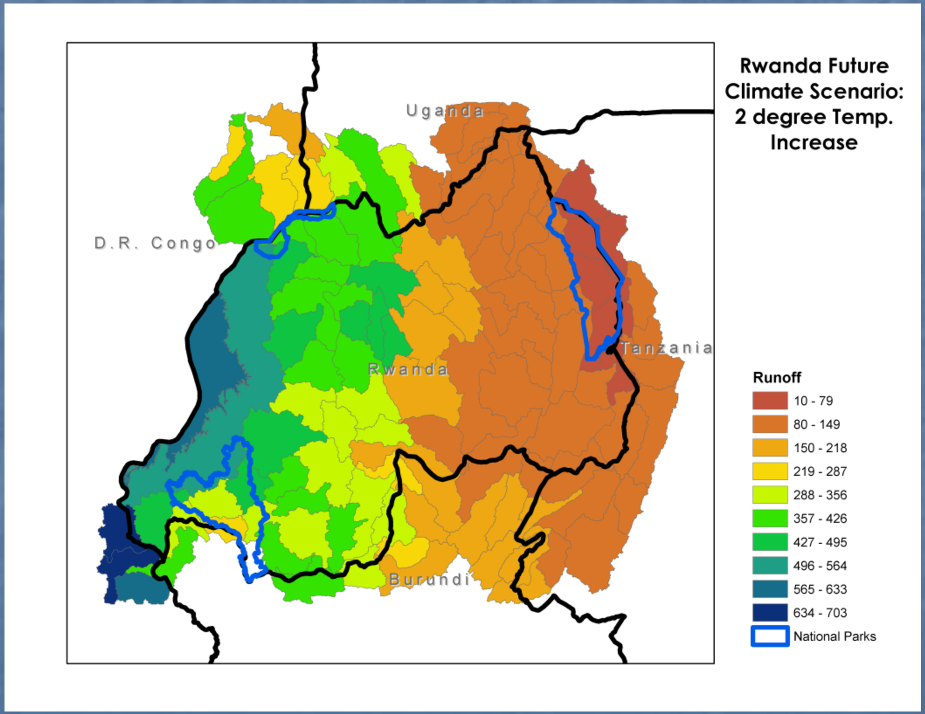


50% Deforestation

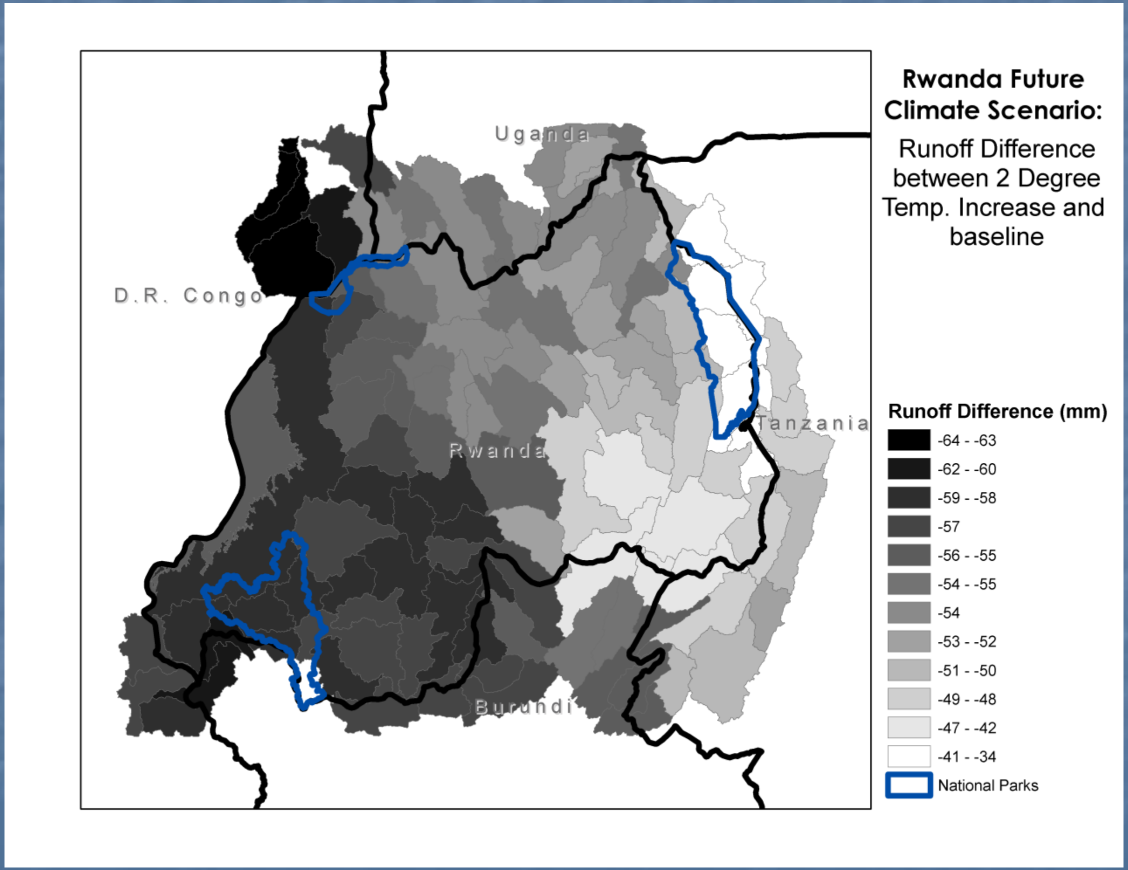


Temp Rise by 2 Degree

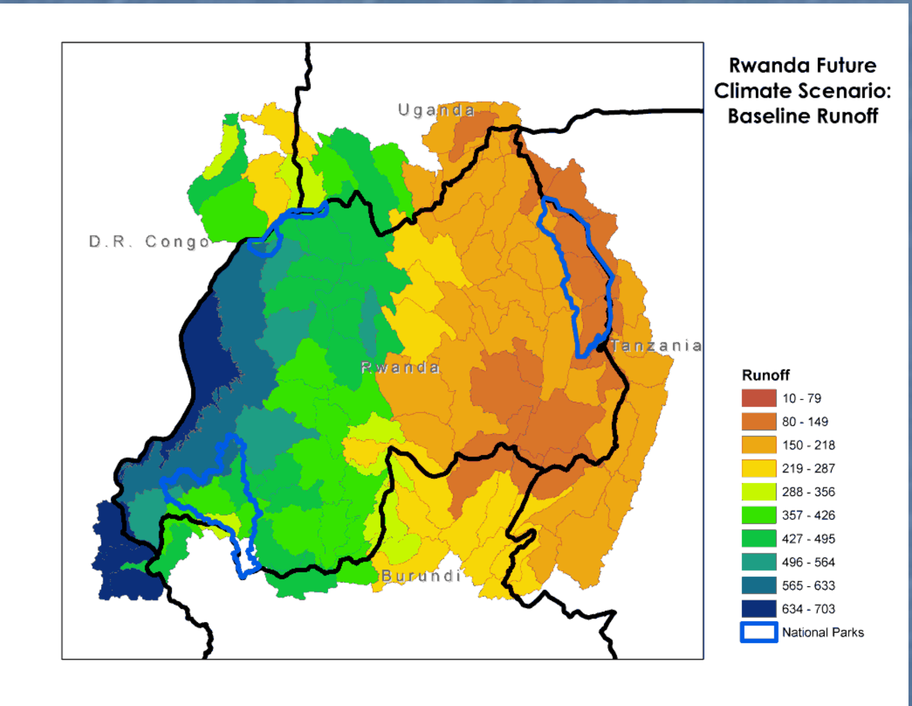


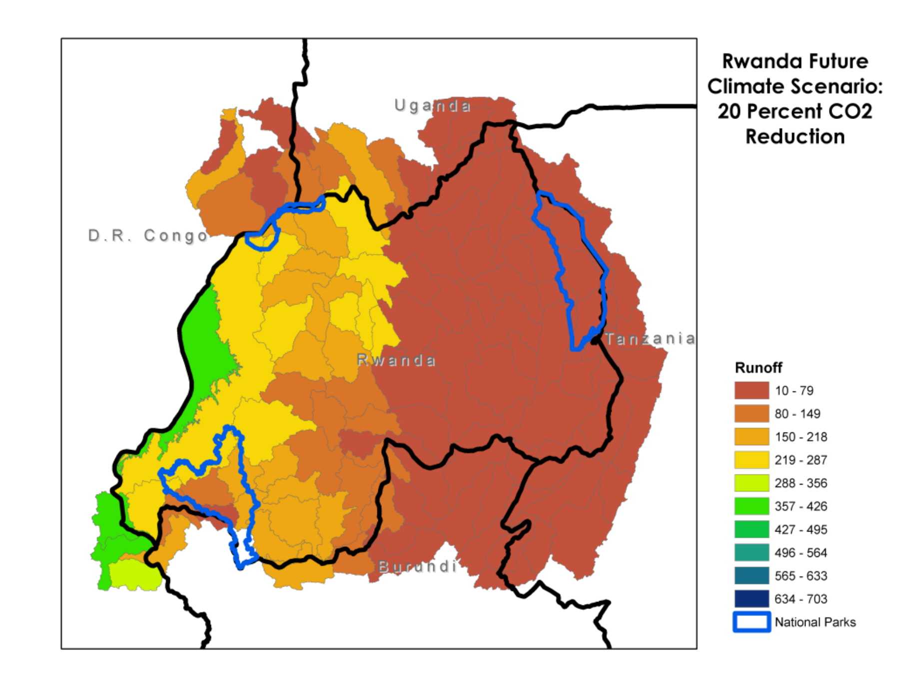


Temp Rise by 2 Degree

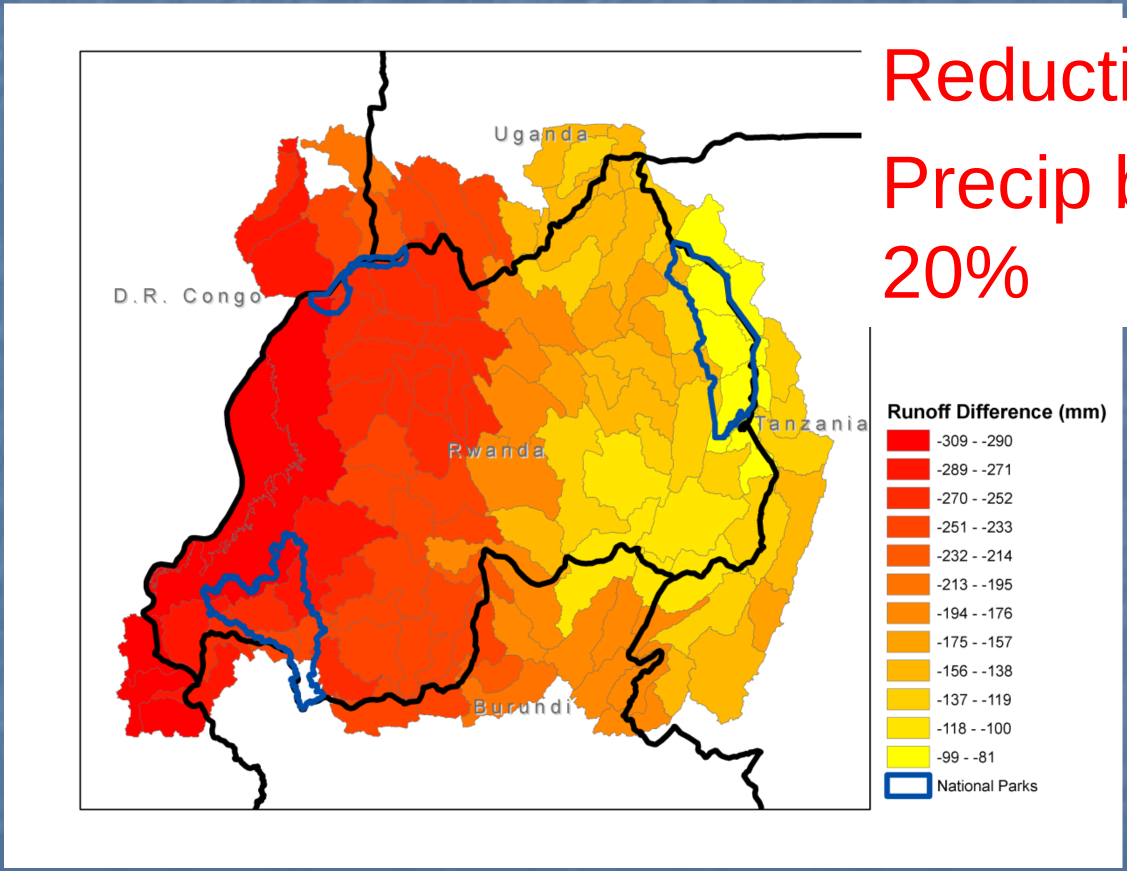


Temp Rise by 2 Degree+20% P reduction





Temp Rise by 2 Degree+20% P reduction



Reduction

Precip by 20%

Summary

- Large spatial distribution of runoff in all three countries, and within the three Basins;
- Large temporal variability of rainfall an runoff;
- The climate change would have serious impacts on water resources in all countries.