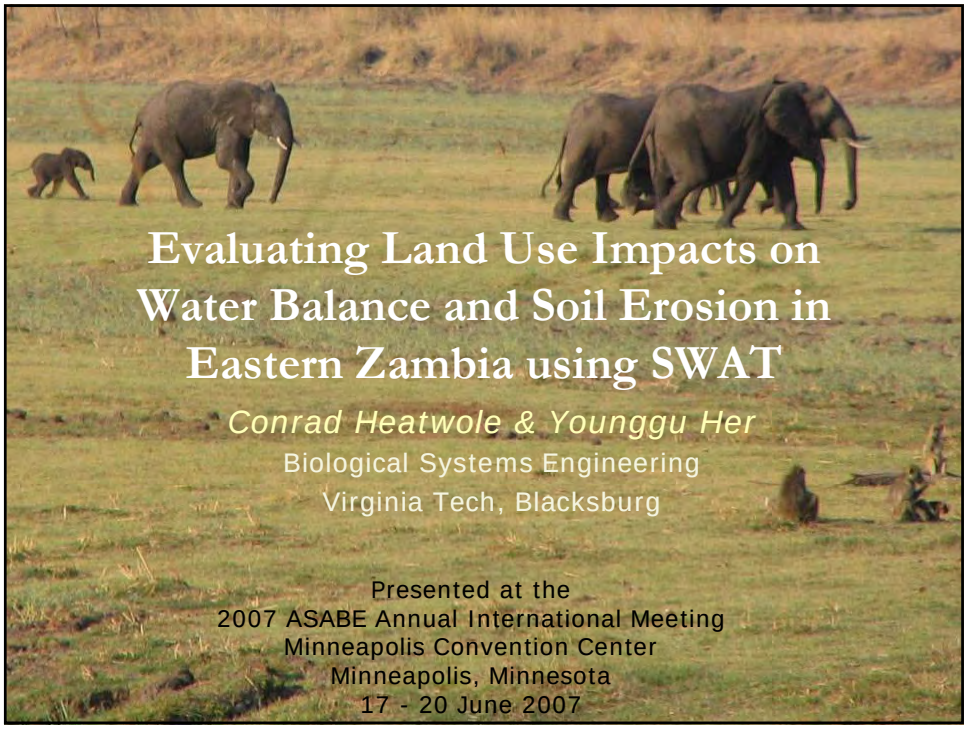


Evaluating Land Use Impacts on Water Balance and Soil Erosion in Eastern Zambia using SWAT

Conrad Heatwole & Younggu Her
Biological Systems Engineering
Virginia Tech, Blacksburg

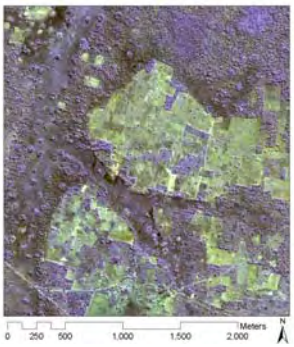
Presented at the
2007 ASABE Annual International Meeting
Minneapolis Convention Center
Minneapolis, Minnesota
17 - 20 June 2007

Background

- **SANREM CRSP**
  - Support decision makers in developing countries
    - By providing
      - Appropriate data, knowledge
      - Tools and methods of analysis
    - By enhancing
      - Capacity to make better decisions to improve livelihood
      - Sustainability of natural resources (SANREM website)
  - Our research
    - Hydrologic Modeling
      - Evaluate the impact of land use changes on water and sediment yield from cropped areas in Eastern Zambia
        - What is the impact of clearing marginal land in the upland areas of the watershed for subsistence agriculture?
    - Utilize available data sources to support modeling
      - Various data sources have been explored

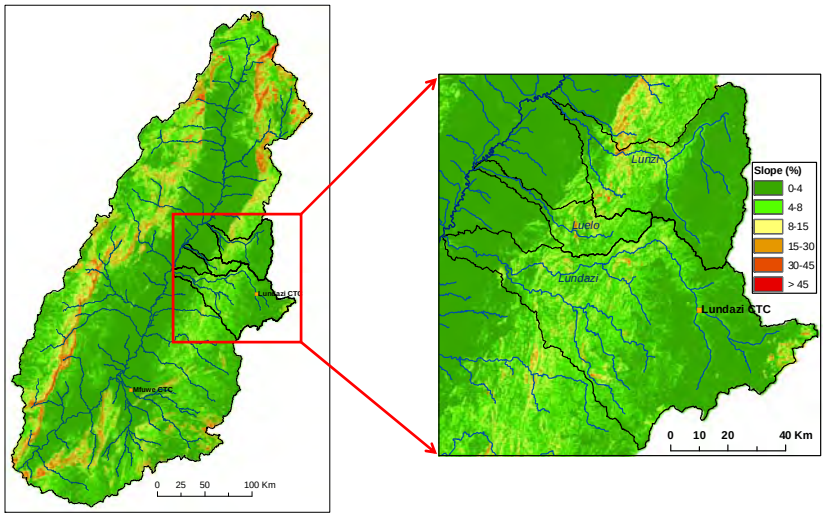
Study Area

- **Lundazi, Luelo, and Lunzi**
  - Located in the Eastern Zambia
    - Crop fields, forest (Miombo & Mopane), and wetland (Dambo)
    - Plateau, hill, and valley (7,345Km^2)
    - Crop fields are encroaching into forest lands on the plateau as fertility declines and old fields are abandoned



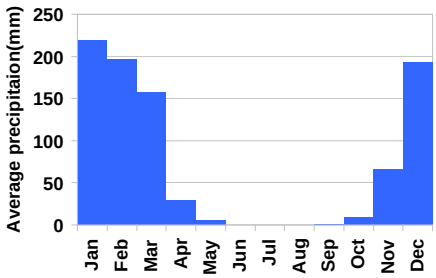
Study Area

- **Three watersheds – Focus for this study**



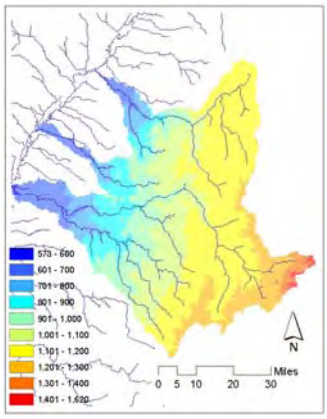
Data

- **Climate**
  - From Zambia Meteorological Service
  - Historical data of 21 years
    - Rainfall and temperature (average, max., and min.)
      - Annual average rainfall : 855mm
      - Maximum daily rainfall : 96.5mm
      - Temperature range : 6 ~ 39°C
    - Distinguished dry and wet season
      - Dry season
        - May ~ Oct
      - Wet season
        - Dec ~ Mar



Data

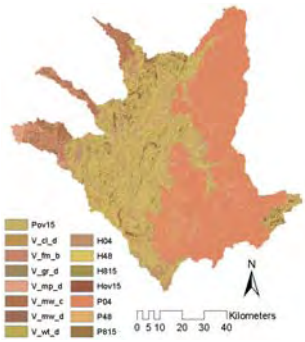
- **Topography**
  - Resampled DEM from finished SRTM-3 (90m)
    - Shuttle Radar Topography Mission for the entire earth of 80%
    - USGS EROS (Earth Resource Observation and Science)
  - Derived properties from the data
    - Average elevation : 1,035m
    - Average slope : 3.73%



- **Stream Line**
  - Extracted from Landsat7 ETM+
    - Virtually from 7-3-2 band combo
  - Derived from the DEM (SRTM-3)
    - Flow accumulation
  - Compared and corrected
    - "stream burning" on the DEM with the extracted stream line

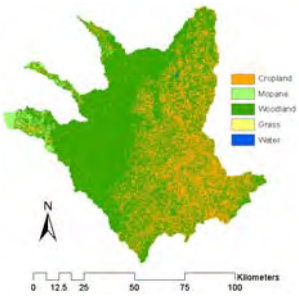
Data

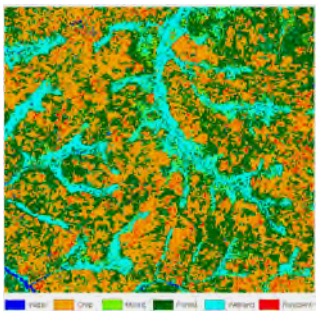
- **Soil**
  - FAO DSMW (Version 3.6, Jan 2003)
    - 26 major soil groupings and 106 soil units
      - 1:5M scale, Covers entire countries in the world
    - Properties acquired from the "Digital Soil Map of the World"
      - Soil texture, drainage level, No. of layers, so on
  - Soil properties of the study area
    - Dominant texture
      - Sandy-clay-loam & loam
    - Regional distribution
      - Plateau : Well drained (Ferrsols)
      - Hill : Moderated drained (Lithosols)
      - Valley : Poorly drained (Luvisols)

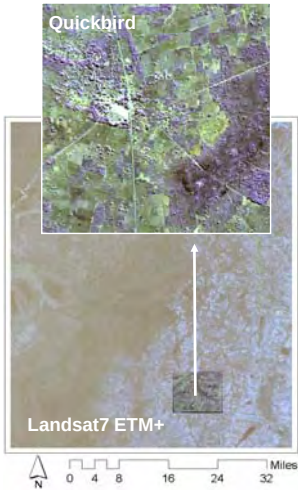


Data

- **Land use**
  - Land use classification
    - Landsat7 ETM+ (30m, May 8 2002)
      - Object data, May 8 2002
    - Quickbird (2.4m, July 23 2002)
      - Reference & groundtruth
    - Primary analysis was used







Hydrologic Modeling

- **Hydrologic simulation model**
  - SWAT (**S**oil & **W**ater **A**ssessment **T**ool, USDA ARS)
    - Watershed scale, continuous (long-term), physically based
      - Contributions of CREAMS, GLEAMS, and EPIC
      - Runoff : SCS-CN method, Sediment yield : MUSLE
    - Interface with GIS software
      - ArcView or ArcMap (Apr 11, 2007)
    - Equipped with broad database
      - Vegetation, fertilizer, pesticide, tilage
      - Mainly developed for agricultural land use of the USA
      - Database matching and development
      - When applying outside the USA, must match supplied database entries with the real world
        - Vegetation; Management practices; Fertilization
        - Soil properties; Climate data
    - Field surveying needed to verify vegetation and drainage
      - Field visits: Nov 2006 and Mar 2007

Hydrologic Modeling

- **Runoff as a function of land use**
  - CNs are assigned based on the best estimates from existing tables of US land use conditions
  - "Hydrologic soil group (HSG)" is not available for Zambia
  - Used slope and physiographic region as surrogate for HSG
    - Low slopes and sandy soils: low runoff potential (HSG=A)
    - Steep slopes have greater runoff potential (HSG=D)

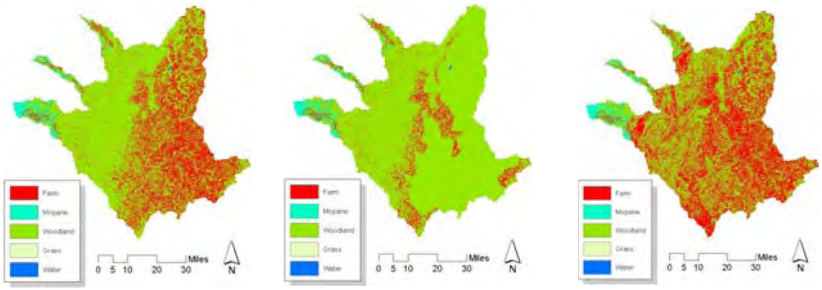
Slope	HSG	0-4%	A	4-8%	B	8-15%	C	>15%	D

From TR-55 manual

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition 2/	A 3/	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48

Hydrologic Modeling

- **Scenarios**
  - Current land use
  - Scenario1
    - No crop land (forest) on the plateau
  - Scenario2
    - Extended crop land
      - Forest on slope < 4% cleared



Results

- **Sensitivity Analysis**
  - For only the parameters related to flow

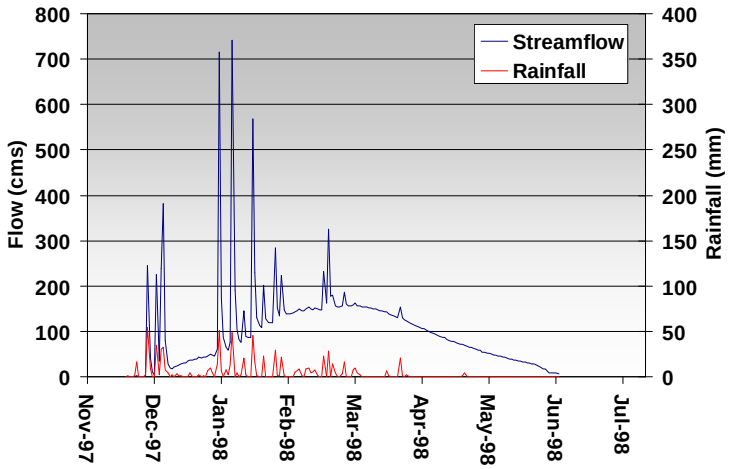
CN2	1	sol_k	8	REVAPMN	15	SMFMN	28
GWQMN	2	BIOMIX	9	GW_DELAY	16	TLAPS	28
ESCO	3	Canmx	10	SLSUBBSN	17	SFTMP	28
rchrg_dp	4	SLOPE	11	Epco	18	SMTMP	28
SOL_AWC	5	Surlag	12	sol_alb	19	TIMP	28
GW_REVAP	6	ALPHA_BF	13	ch_n	20	blai	28
sol_z	7	CH_K2	14	SMFMX	28		

  - For the all parameters related to flow, sediment, and water quality

CN2	1	SLOPE	12	USLE_C	23	blai	42
GWQMN	2	surlag	13	USLE_P	24	SPCON	42
ESCO	3	ALPHA_BF	14	SOL_NO3	25	SPEXP	42
SOL_AWC	4	CH_K2	15	SOL_LABP	26	CH_COV	42
rchrg_dp	5	SOL_ORGN	16	SOL_ORGP	27	CH_EROD	42
GW_REVAP	6	GW_DELAY	17	SMFMX	42	PPERCO	42
sol_z	7	SLSUBBSN	18	SMFMN	42	PHOSKD	42
sol_k	8	sol_alb	19	TLAPS	42	gwno3	42
REVAPMN	9	epco	20	SFTMP	42		
BIOMIX	10	NPERCO	21	SMTMP	42		
canmx	11	ch_n	22	TIMP	42		

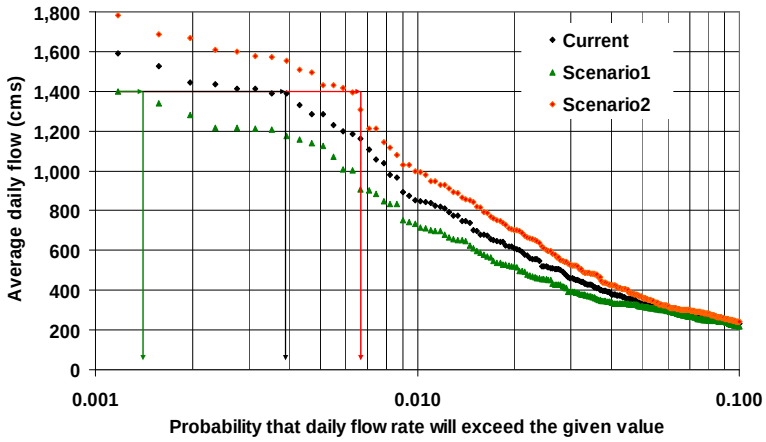
Results

- **Seasonal variation of flow (Lundazi)**



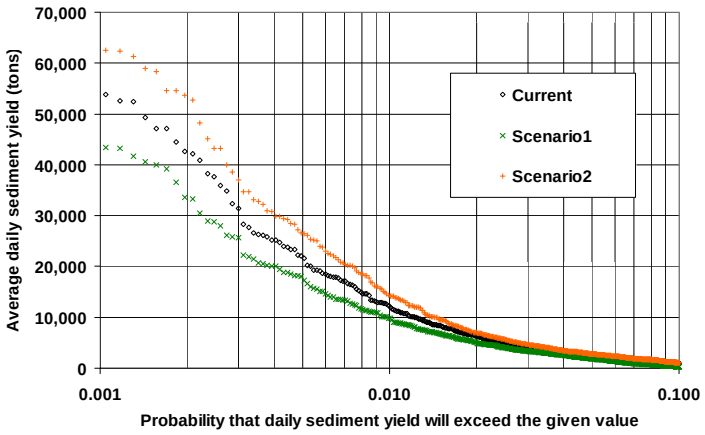
Results

- **Flooding probability for 3 scenarios**



Results

- **Sediment yield probability for 3 scenarios**



Primary Conclusions

- Agriculture is the best in the plateau area
  - Good soils, low slopes and runoff
    - Dambos are providing natural filtering and flow attenuation function
- Dambos and their functions in the landscape should be preserved
- Hill region has higher runoff and erosion due to steeper slopes and shallow less-permeable soils
- Improving sustainability and productivity of upland cultivation benefits all valley ecosystems

Next Steps in the Study

- **Land use data**
  - Too few classes, limited spatial extent
  - Detailed aerial/satellite imaging, improved sampling
- **Soil data**
  - Only very broad soil classification is available
  - More detailed local knowledge exists (SANREM study)
- **Hydrologic parameters**
  - Our understanding of hydrology is limited and parameters to quantify differences are assumed
  - Monitoring studies at field and watershed scales are needed to provide critical data
- **Weather data**
  - Need a network of rainfall observation locations

Acknowledgements

This work is part of the Watershed Modeling and Assessment component of the USAID-funded SANREM-CRSP program at Virginia Tech, and a collaboration with Alex Travis (Cornell University) and Dale Lewis (Wildlife Conservation Society) of the SANREM-CRSP Zambia project.

Contact

heatwole@vt.edu
zorbist@vt.edu