Effects of Landuse and Climate Change on Water Yield of a Coastal Forested Watershed using SWAT Model

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Cooperator:
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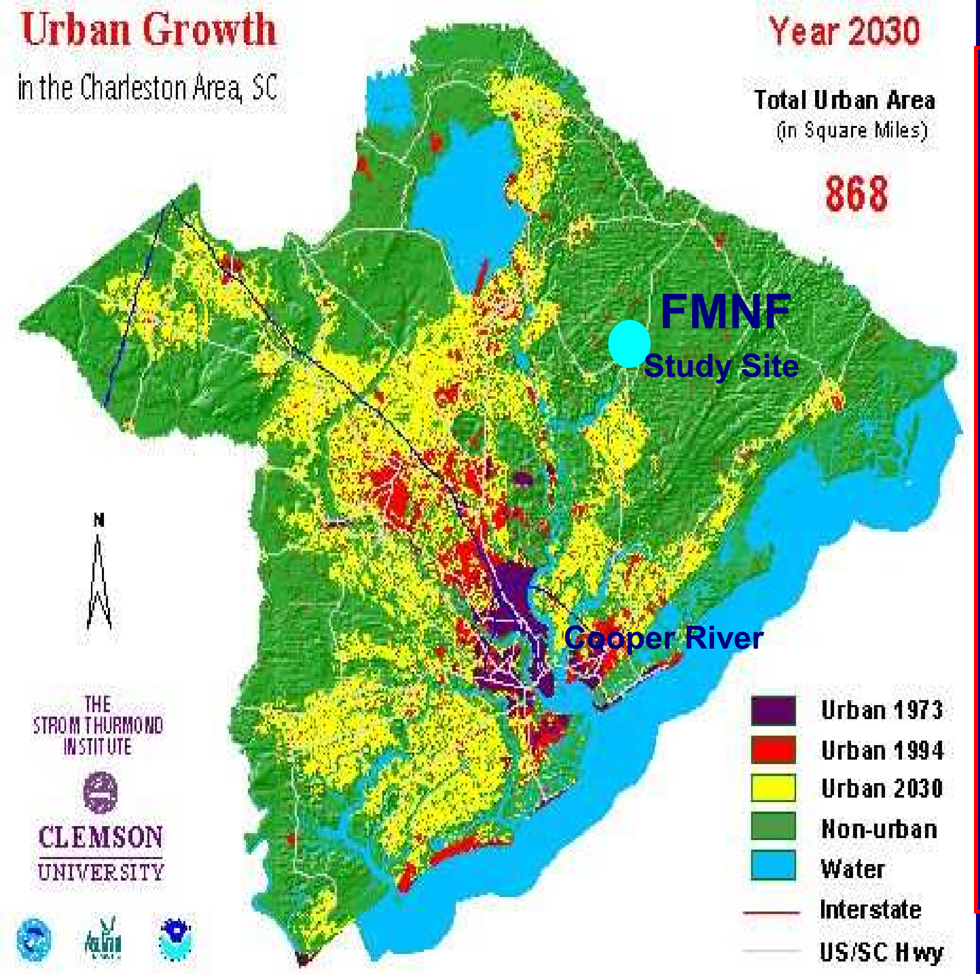
LOWER COASTAL PLAIN FORESTS

HYDROLOGIC CHARACTERISTICS

- Low gradient, Poorly drained
- Shallow water table
- Surface-Subsurface drainage
- Rainfall > PET
- Humid – ET dominated
- Highly productive
- Rapid urbanization
- Close to estuaries
- Vulnerable to water quality
- Watershed boundaries
- Dendritic streams
- Depressional/Riparian
- GW –Surface water interaction
- Tropical storms/Hurricanes
- Tidal & Backwater
- Flow and loading measurements
- Poorly Studied

SOUTH CAROLINA COASTAL PLAIN

Project Urban Growth 1970-2030 Charleston Area and Francis Marion National Forest, SC



- Headwaters of Cooper River Basin (Charleston)
- Rapidly growing urbanization
- Support sustained fresh water and unique ecological diversity
- At the Wildland-Urban Interface
- Accurate understanding of hydrologic processes as a reference system

IMPACT ASSESSMENTS

- Land Use Change (Silvicultural, Agricultural, and Urbanization)
- Climate Change, Sea Level Rise
- Long-term monitoring – impractical
- Modeling – the most cost effective tool when calibrated/validated
- MIKESHE, PRMS, DRAINWAT, SWAT
- SWAT (USDA-ARS Soil & Waster Assessment Tool) Arnold et al (1998)

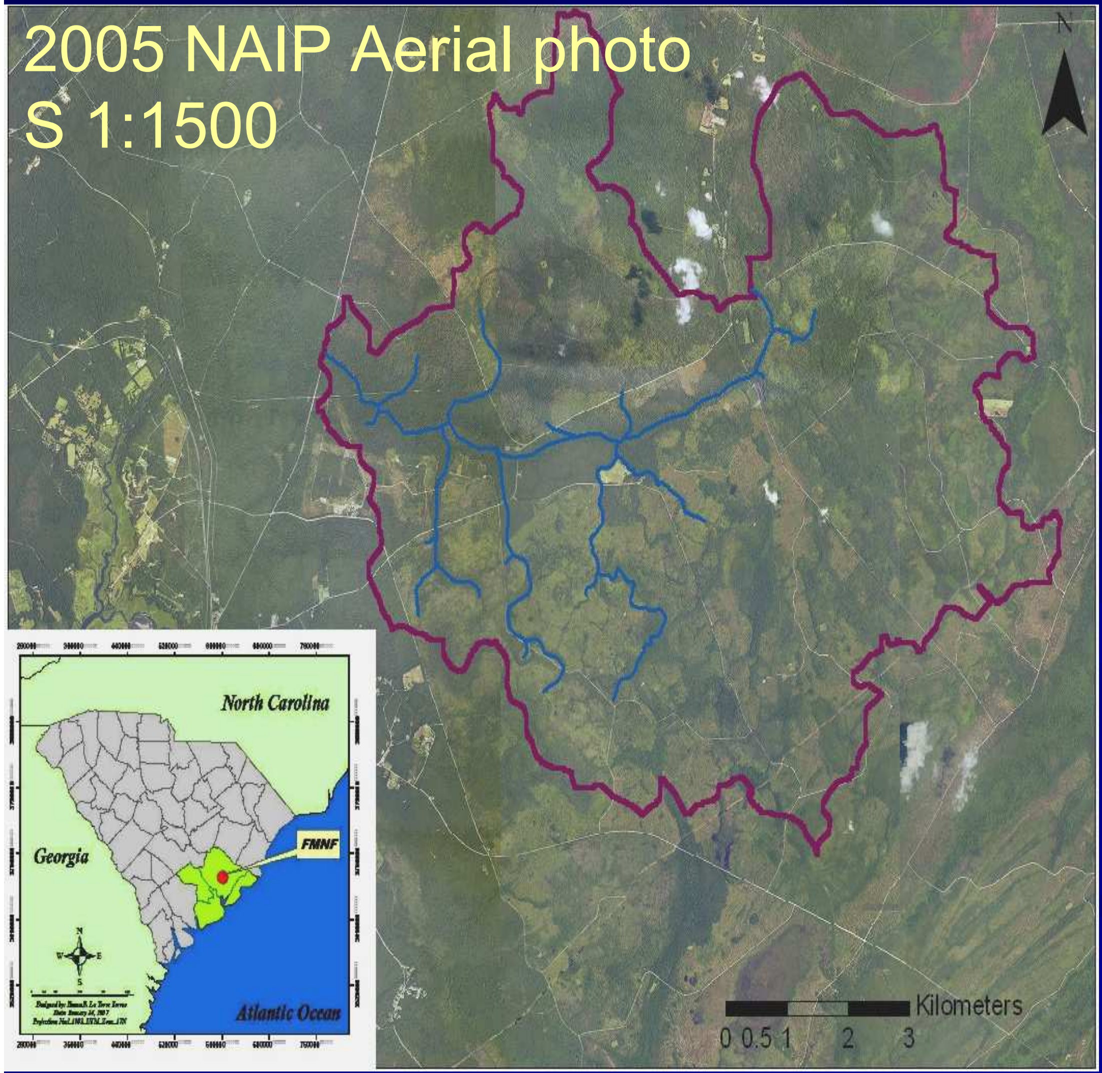
MOTIVATION Using SWAT

- Semi-Process-based, watershed-scale
- Worldwide multi-objective applications including landuse and climate change (Gassman et al., 2007)
- Easily available GIS and climatic data
- Predicts Stream flow, GWF, ET, SM
- *Very limited application on low-gradient coastal plain especially, forests and urban areas*
- Wu and Xu (2006) – Successful application on 3 large coastal forest (<67%) watersheds, LA
- SCS-CN, ESCO, and Manning “n”- Sensitive

OBJECTIVE

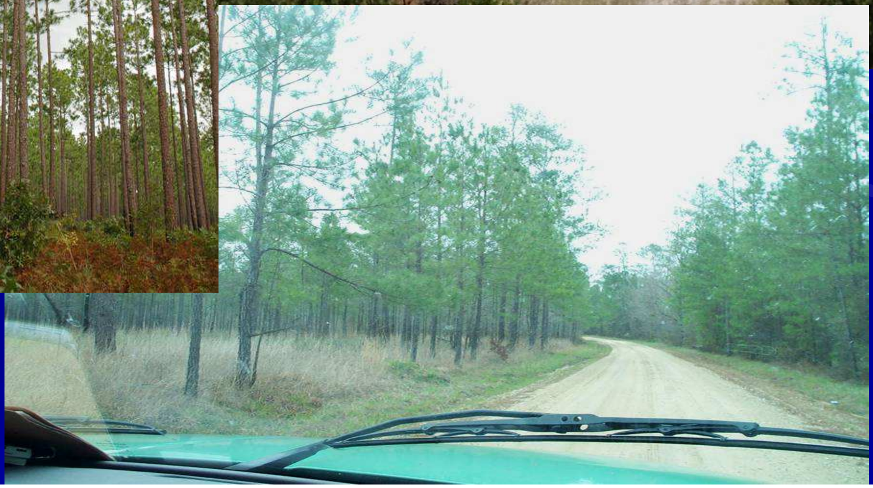
- To test the SWAT model's ability to predict daily (for urban) and monthly stream outflows for a low-gradient coastal forested watershed with minimum field measurements using calibration and validation methods for its further application for evaluating land use and climate change effects later

TURKEY CREEK WATERSHED

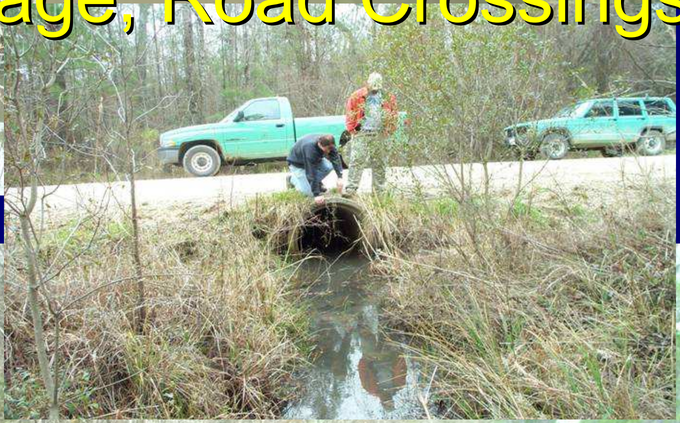


- 7,250 ha (72.5 km^2)
- 96% Forests & wetlands
- USDA FS, 1964
- Long-term data
- 3rd order, 11.4 km stream
- 6.7 km^2 water/wetlands
- 4 m to 14 m a.m.s.l.
- ~ 1370 mm rainfall
- T_{avg} = 18.4^{o}C
- 1100-1200 mm PET

Various Types of Pine Forest Stands

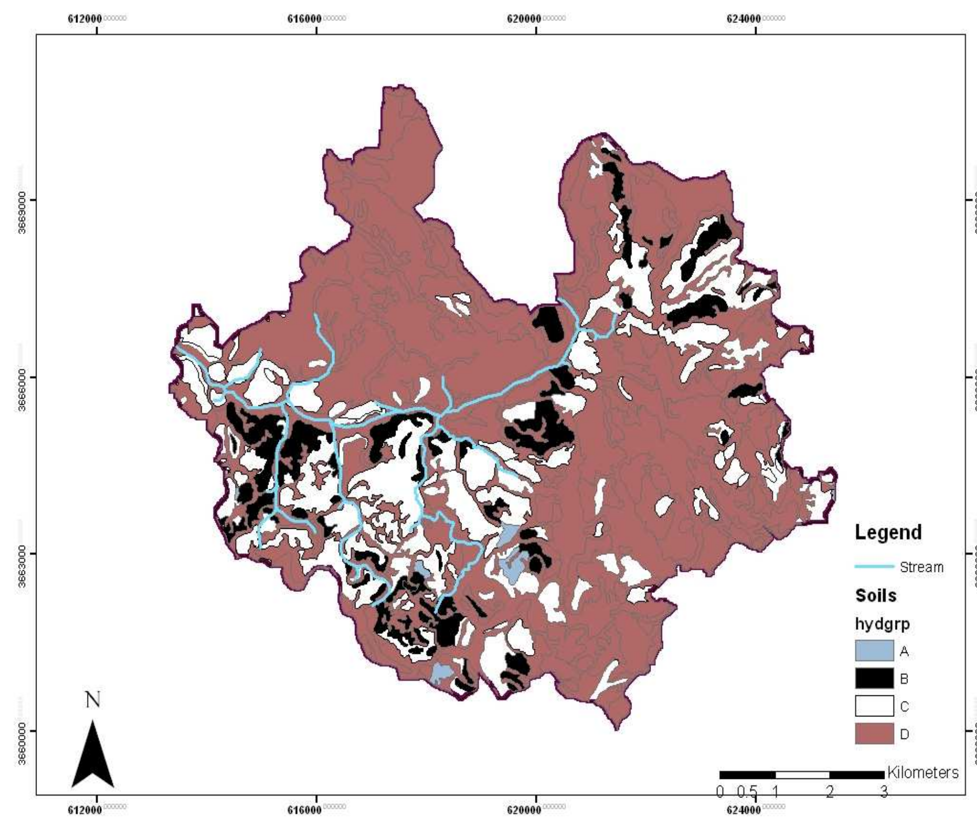


Drainage, Road Crossings, Riparian & Water Features

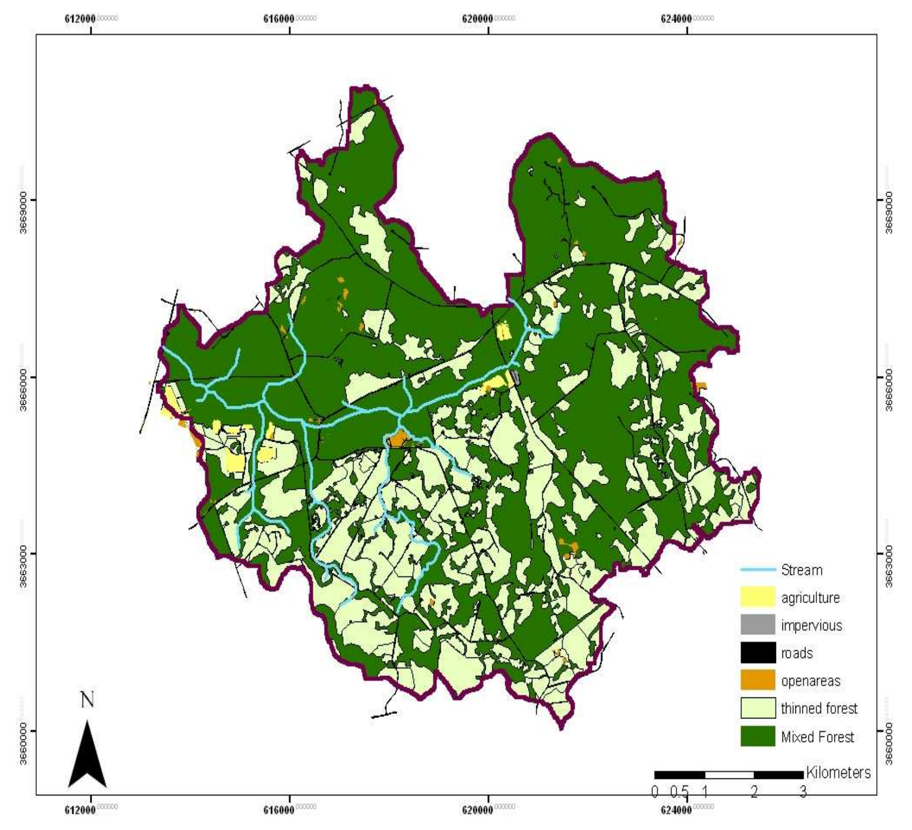


SOILS & LAND USE

NRCS SSURGO Soils map1:24000

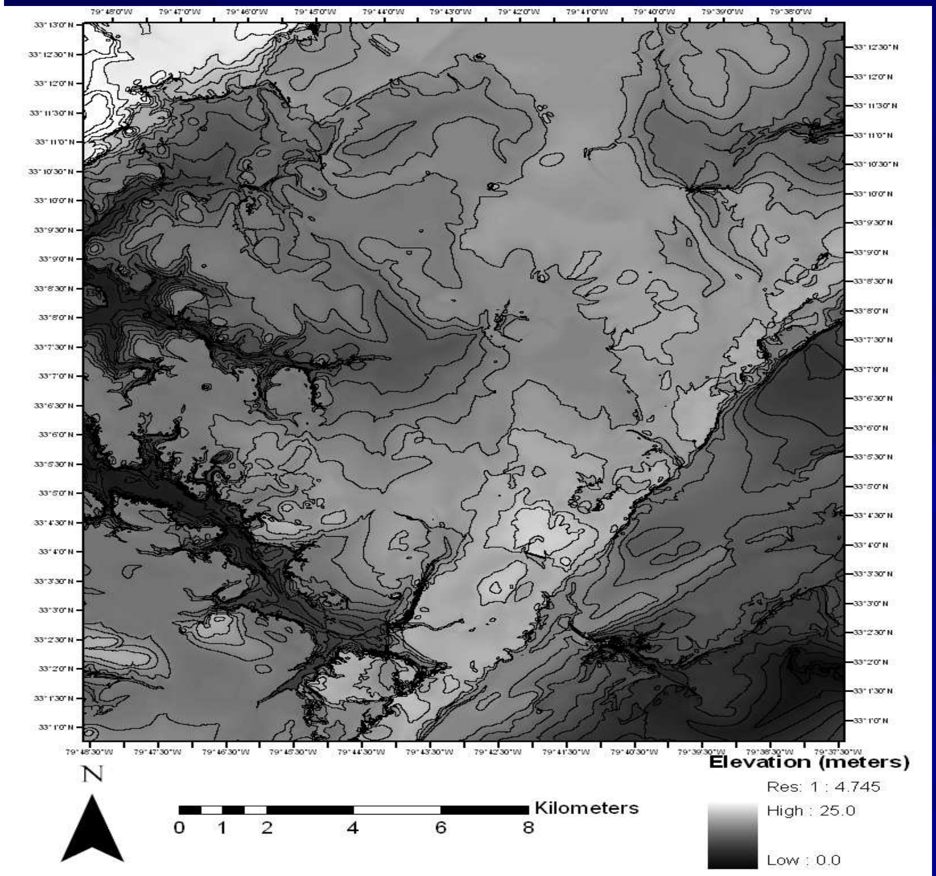


Land use using 2005 Imagery 1:1500

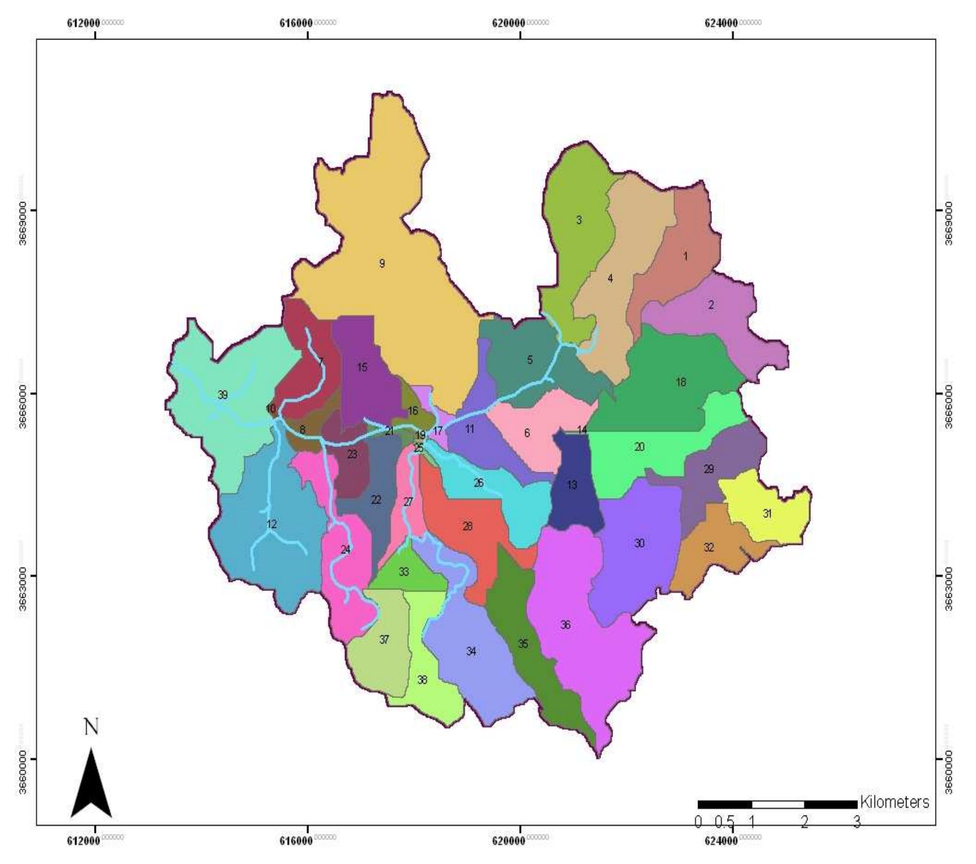


DEMs & Watershed Delineation

2005 USGS 1:24,000, 10mx10m DEM



- 39 Subbasins
- 213 HRUs



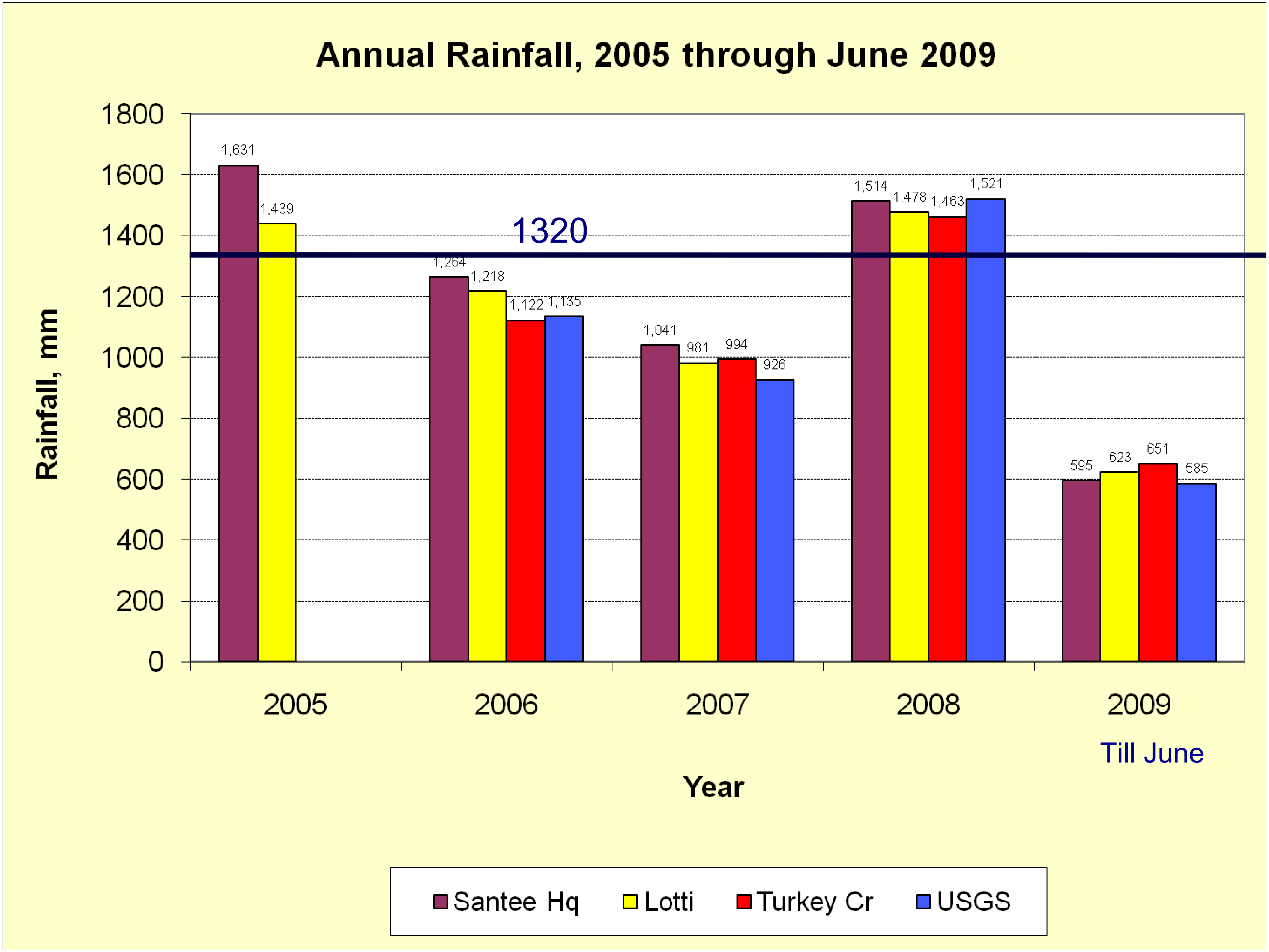
Monitoring Stations

USGS gauging station at watershed Outlet: Rain gauge, Flow monitoring and water quality sampling station

Complete Weather Station with a rain gauge. Weather data for estimating daily P-M PET

TEMPORAL INPUTS & DATA

- Daily rainfall from three auto gauges calibrated using manual data
- Penman-Monteith (P-M) Daily PET for a grass reference using weather data **(Limitation)**
- Daily stream flow at the outlet
- Base flow – Autofiltering **(Arnold et al., 1999)**
- All measured data for April 2005- May 09
- 2003-05 : as a “warm-up” period

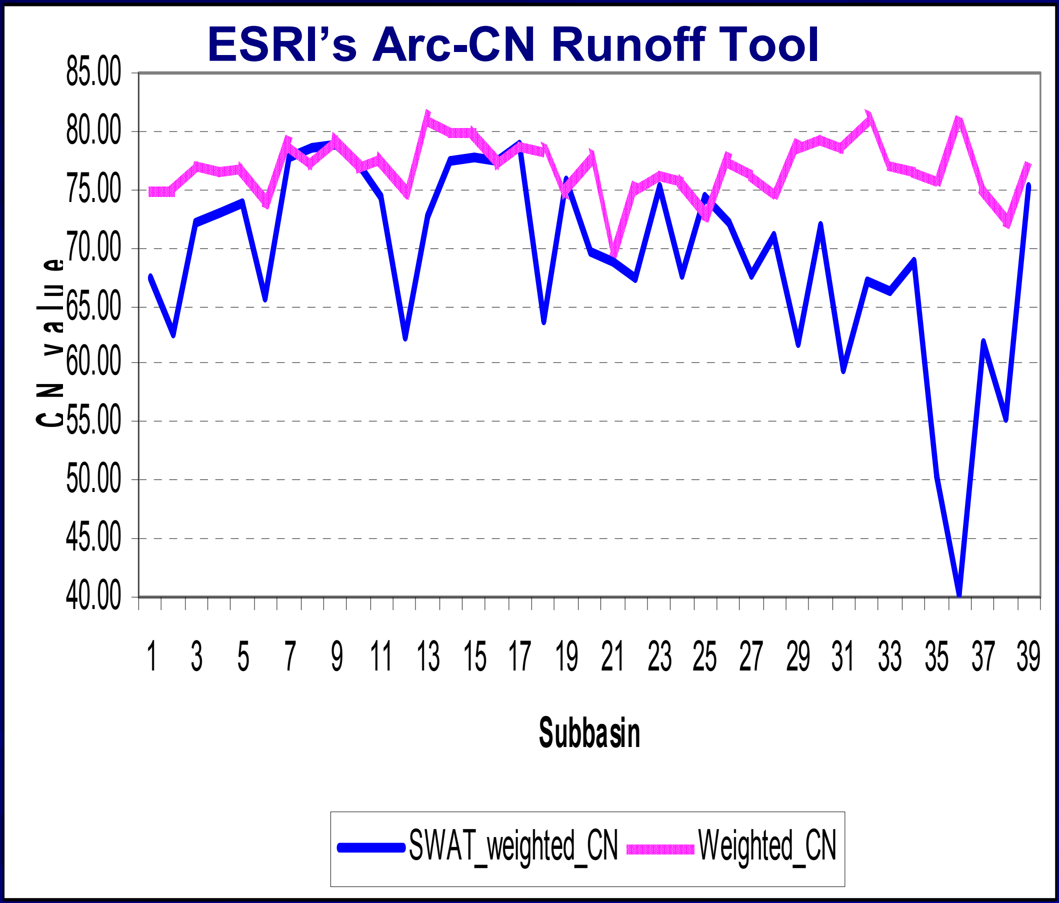


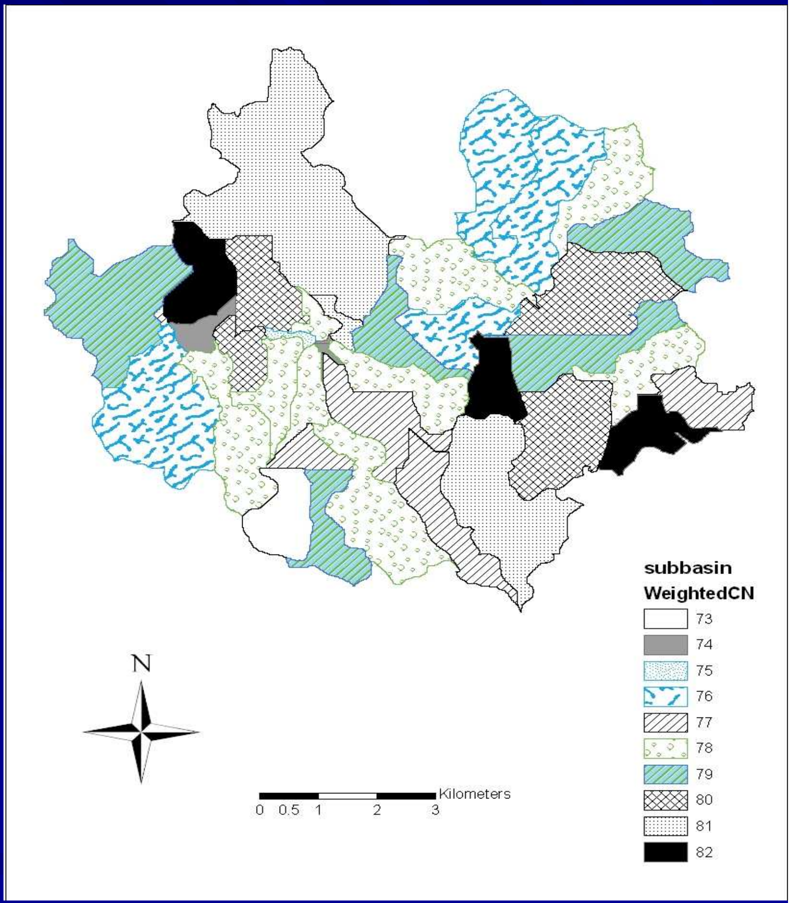
Annual Rainfall, 2005 through June 2009
Rainfall, mm
1800
1600
1400
1200
1000
800
600
400
200
0
1,631
1,439
1320
1,264
1,218
1,122
1,135
1,041
981
994
926
1,514
1,478
1,463
1,521
595
623
651
585
2005
2006
2007
2008
2009
Till June
Year
Santee Hq
Lotti
Turkey Cr
USGS

ASSUMPTIONS

- ET – major water loss (~70-80%): f(PET, LAI, AWC)
- Stream Flow = SRO + BFLO – TRLoss
- Base Flow = ~ 30% of Streamflow (Estimated)
- SCS CNs based on major forest type (73-82)
- SOL_AWC, K_{sat} based on SSURGO data
- Improved CN for continuous SM accounting using a depletion coefficient (Kannan et al., 2007)
- Growing season: Mar 01 – Nov 30
- Flow routing: Muskingum method

SWAT & Arc-CN Curve Numbers





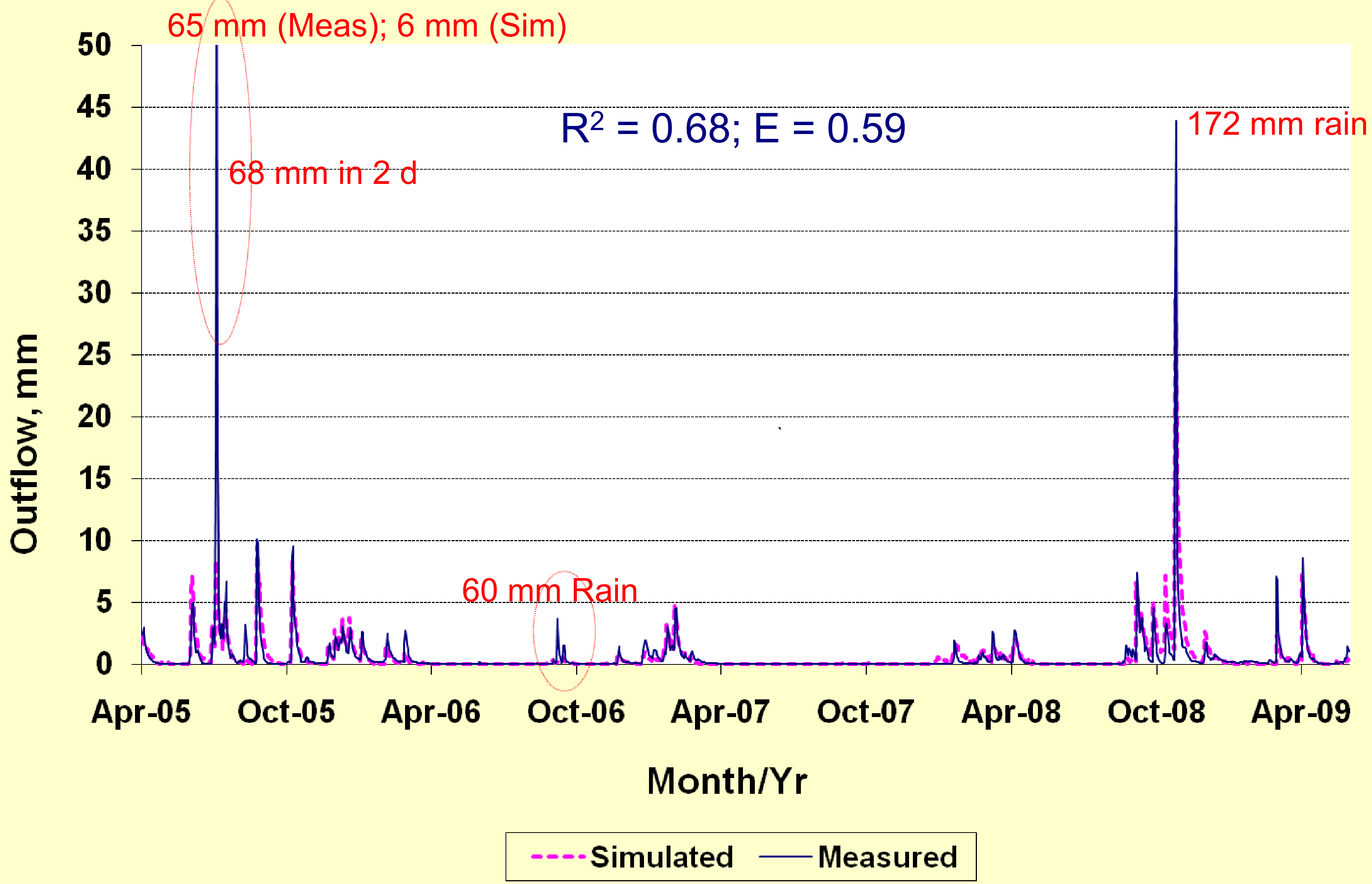
Calibrated Input Parameters

Parameter	Description	Calibrated Value
CN	Curve Number	Variable
ICN	CN calculation as a function of plant ET	1.0
CNCOEF	Plant ET Curve Number coefficient	0.10
ESCO	Evaporation Soil Compensation Factor	0.80
EPCO	Evaporation Plant Compensation Factor	0.1
GW_REVAP	Groundwater “revap” coefficient	0.02
CH_N(1)	Manning’s Roughness in main channel	0.10
CH_N(2)	Mannings roughness in tributaries	0.15
OV_N	Manning’s roughness in overland flow	0.5
SOL_AWC	Soil available water content	0.4
ALPHA_BF	Alpha baseflow	0.5
SURLAG	Surface Runoff Lag Coefficient	1.50
CNMAX	Maximum Canopy Storage	0.50

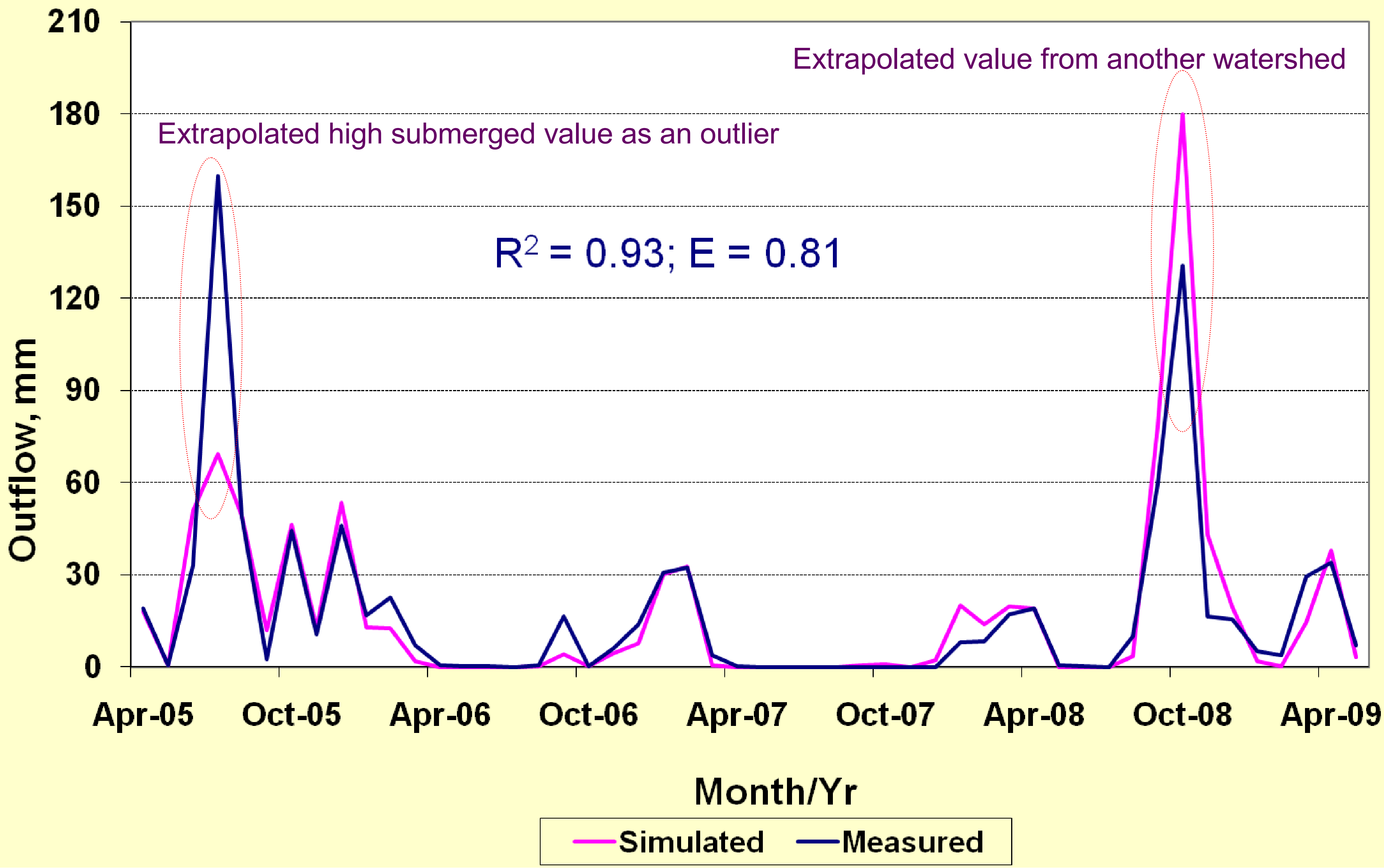
MODEL EVALUATION CRITERIA

- Measured & Predicted Outflows
- Graphical Comparisons (Daily, Monthly)
- Coefficient of Determination (R^2) (Monthly)
- Nash-Sutcliffe Efficiency (E) (Monthly)
- Average Absolute Deviation (AAD) (Monthly)
- Average Deviation (Monthly)

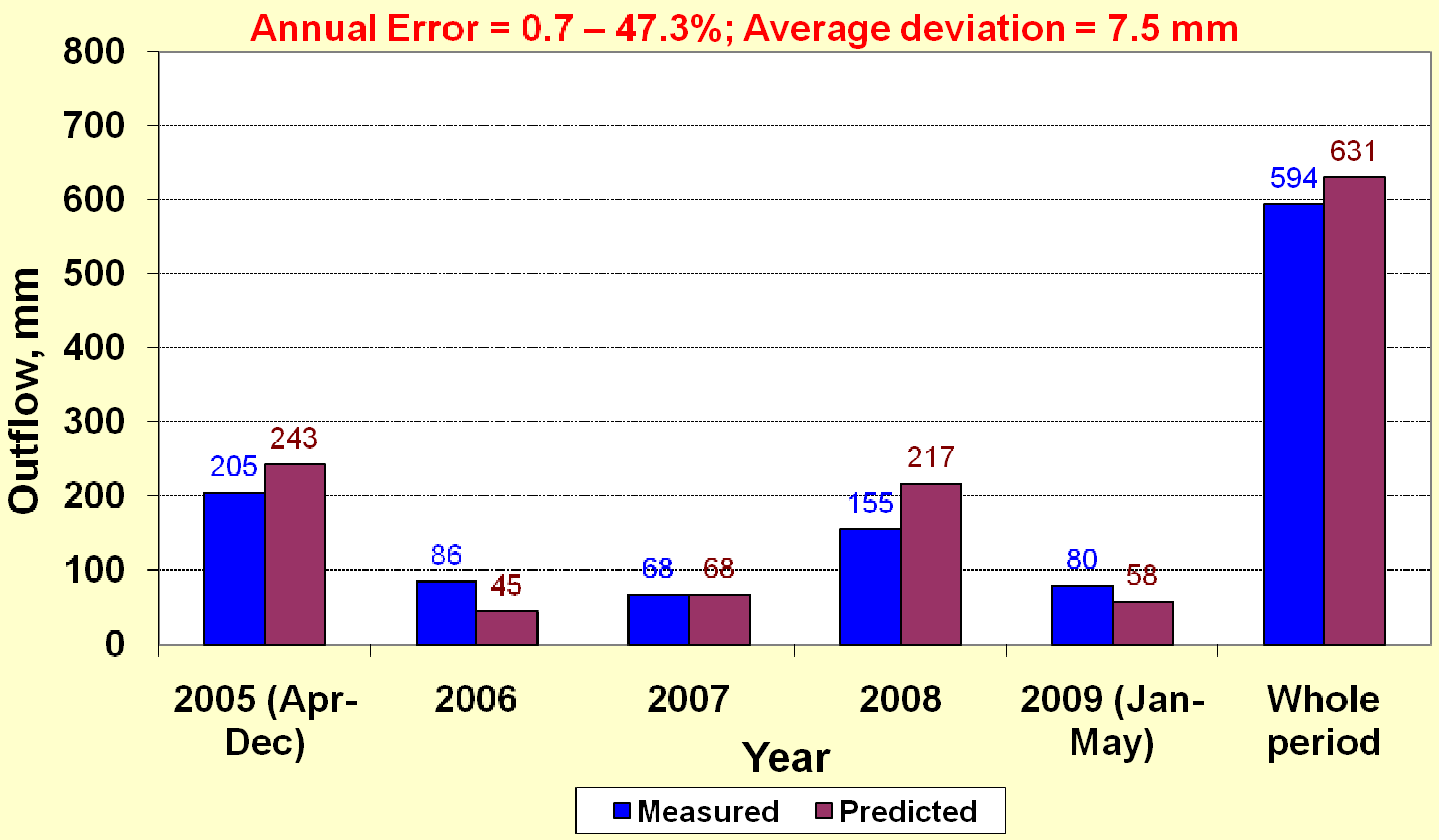
Measured & Predicted Daily Flows (2005-09)



Measured & Predicted Monthly Flows (2005-09)



Measured/Predicted Annual Streamflow for 2005-09



Model Evaluation Statistics

Red values for Daily

Monthly	R^2	E	Avg Abs Dev (mm)	Avg Dev (mm)	Error (%)
Apr 2005 –May 07 (Calibration)	0.91 0.77	0.87 0.76	3.4 0.23	-0.3 0.02	-1.9
Jun 2007-May 09 (Validation)	0.96 0.64	0.78 0.27	4.8 0.28	1.9 -0.16	18.8
All: 2005 - 09	0.93 0.68	0.81 0.59	4.1 0.26	0.8 -0.06	6.3

Predicted Water Balance Parameters

Year	2005	2006	2007	2008	2009 (Jan-May)	Average (2005-08)
Precipitation, mm	1509	1136	993	1466	444	**1276**
Water Yield, mm	**381**	**48**	**70**	**406**	**61**	**226 (18%)**
Surface runoff, mm	313	32	39	256	47	**160**
Baseflow, mm (% of Water Yield	74 (19%)	18 (36%)	32 (45%)	153 (37%)	15 (22%)	**69 (30%)**
PET, mm	1165	1231	1178	1134	414	**1177**
AET, mm	**1011**	**1010**	**846**	**931**	**334**	**950**

Application on Study Site for Land Use Change Effects

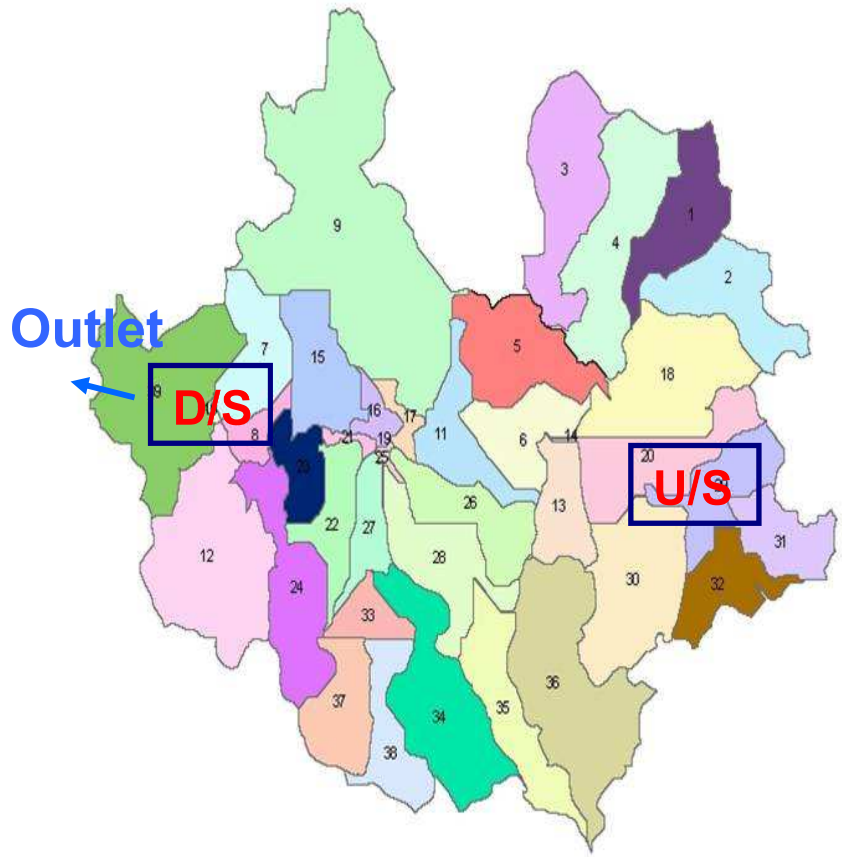
Conversion of Current Subbasins with Forest Landuse to Urban Areas

10, 25, and 50% - U/S & D/S

Varying Impervious areas

Increased outflow due to increased surface R/O, decreased base flow & ET>

Higher CN, lower “n” and storage for urban areas w/increased IA



Land Use Effects by Various Studies

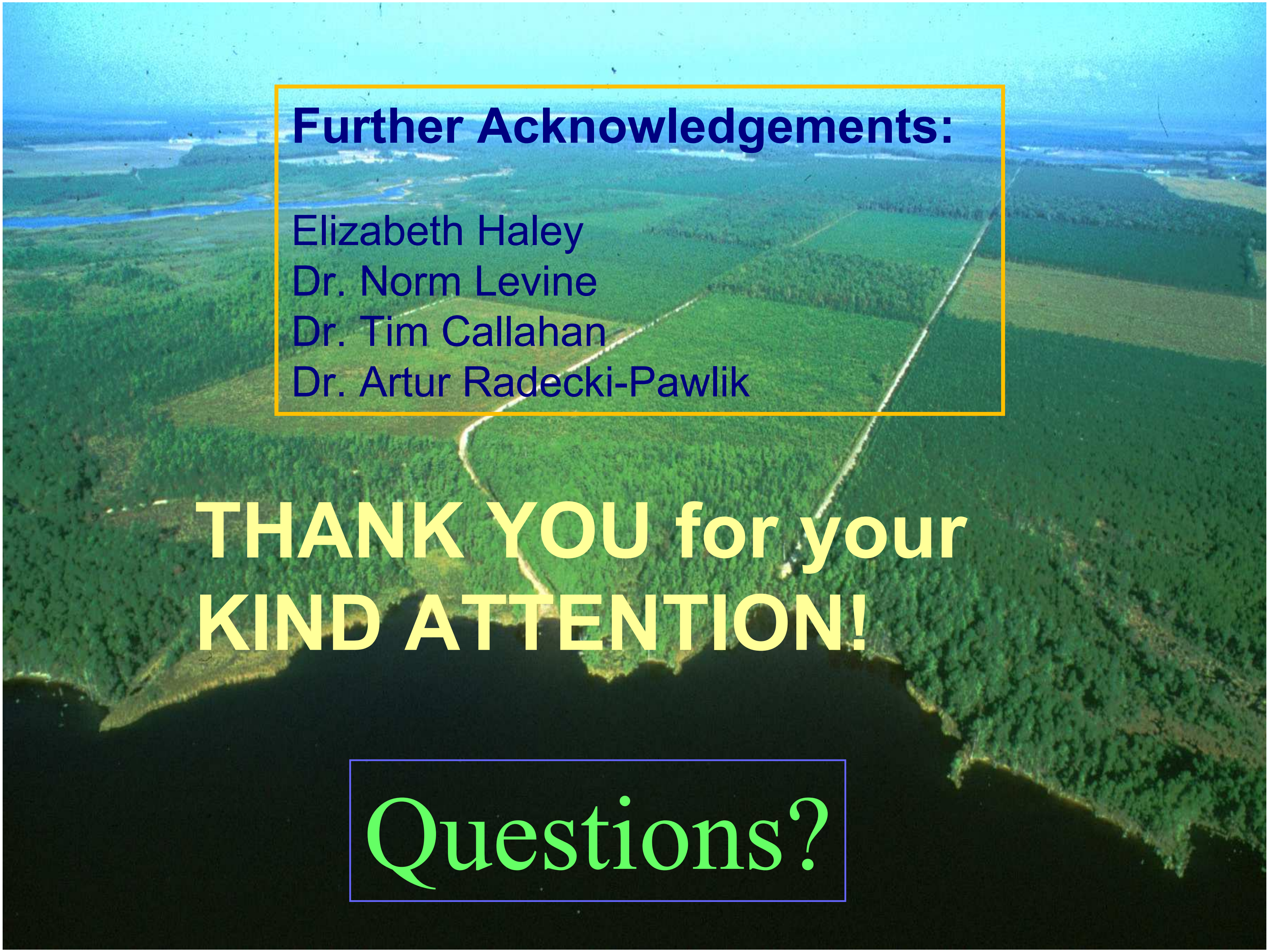
Study	Site Name	Site Area, km²/% Forest	Model used	Data period	Mean annual rainfall/Runoff, mm	Increase in Streamflow, mm (%)
Qi et al (2009)	Trent River watershed, Coastal NC	377/66	USGS PRMS	20 yrs (1981-01)	1300/426	59 (14)
Dai et al (2009)	Control watershed, WS80, Coastal SC	1.6/100	DHI- MIKESHE	3 yrs (2003-06)	1270/269	113 (30)
Dai et al (2008)	Control watershed, WS80, Coastal SC	1.6/100	DRAINMOD	3 yrs (2003-06)	1270/269	122 (35)
Amatya et al (2008)	S4 watershed, Parker Tract, Coastal NC	30/98	DRAINWAT	40 yrs (1951-00)	1288/308	86 (31)
Amatya et al (2007)	Turkey Creek watershed, Coastal SC	72/96	EMPIRICAL: Rain, Canopy, PET	13 yrs (1964-76)	1320/350	208(60)
Fernandez et al. (2007)	S4 watershed, Parker Tract, Coastal NC	111/50	DRAINMOD-based	30 yrs	1354/437	57 (16)

Summary & Conclusions

- SWAT - 72 km^2 lowland watershed- 97% forest
- GIS spatial data (DEM, soils, LULC, Hydrography)
- Both calibration and validation with 4-year data provided acceptable results (E > 0.78; R^2 > 0.91)
- Sensitive to CN, ESCO, “n”
- May under-predict after long dry periods
- Inability to accurately simulate R/O from wetland and riparian areas on the watershed
- Possible errors in estimating forest ET
- Uncertainty in measured data for large storms on the flat, low-gradient streams

NEXT STEPS

- Further refinements in data and parameters for prediction enhancement w/uncertainty component
- Testing with longer period of data (1964-76)
- Application with Land Use Change scenarios for Urban development
- Application with Climate Change scenarios: HadCM3 and CGCM2 GCMs (Qi, S., G. Sun & others, 2009; Amatya et al., 2008)
- Comparison with past studies in the region; Qi et al (PRMS model) > 38% increase in water yield by 20% increase in urban area



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Questions?