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Effect of land use on mean annual streamflow at regional scale

Liem T. Tran
Geography Department

Introduction

- Issue of scale in hydrology and hydrologic modeling
- Framework: Regional Hydrologic Modeling for Environmental Evaluation (RHyME^2)
- Effects of land use on mean annual streamflow at regional scale

Challenges to Hydrology

- Beven (1987)'s *Towards a new paradigm in hydrology*:
  - "… *complexity at small scales leading to relative simplicity (the hydrograph) at large scales. Little or no success has been gained in relating the former to the latter…*
  - *"It is indicative of an impending theoretical crisis in hydrological science that we have made little progress in relating the former to the latter."*

Challenges to Hydrology

- The problem of scale in hydrology:
  - Inherently linked to the problems of nonlinearity, heterogeneity, and nonequilibrium
  - Different viewpoints on the issue of scale in hydrology:
    - Beven (2001)'s "How far can we go in distributed hydrological modelling?": "*scaling theories will ultimately prove to be impossible and that is therefore necessary to recognise the scale dependence of model structures*"
    - Blöschl (2001)'s "Scaling in hydrology": "…*scaling work should materialize as a unifying theory of hydrology—a theory so urgently needed—for which I believe the scaling ideas must be the cornerstone*"
- Consensus: need to identify the "dominant process controls" at different scales

Hierarchy Theory

- A theory of scaled systems developed primarily in the context of general systems theory in 1960's
- Key point immediately relevant to the issue of scale:
  - Structure based on differences in rates:
    - Organization results from differences in process rates
    - A complex system can be decomposed into organizational levels and into discrete components within each level
    - Vertical structure in hierarchical systems: behaviors at higher organizational levels occur at slower rates; lower organizational levels exhibit rapid rates
    - Horizontal structure in hierarchical systems: can be decomposed into subsystems

Practicing Hierarchy Theory in Hydrologic Modeling

- Framework: Regional Hydrologic Modeling for Environmental Evaluation (RHyME^2)
  - Hierarchical structure/scaled system:
    - Recognize the hierarchical structure of hydrologic system
    - Differentiate hydrologic processes/mechanisms at different spatio-temporal scales
  - Nonequilibrium dynamics and metastability:
    - Deal with nonequilibrium and metastability of hydrologic system in the context of hierarchical structure/scaled systems

Study Area

- Part of EPA's Future Midwest Landscape (FML) project
- Upper Mississippi River Basin

Mean Annual Streamflow Model

- Mean annual incremental flow Qi of catchment i:

$$Q_i = e^{\beta_0} X_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} ..(\sum_{k=1}^{n} m_k \%LC_k + 1)\gamma \qquad (1)$$

  - X_j, are the climatic and geomorphologic characteristics of catchment i
  - β_i, i=0,…m, are model coefficients
  - $\%LC_k$, k=1,…n, are percentage of LULC k in catchment I
- Linearize (1) and solve with spatial error model:

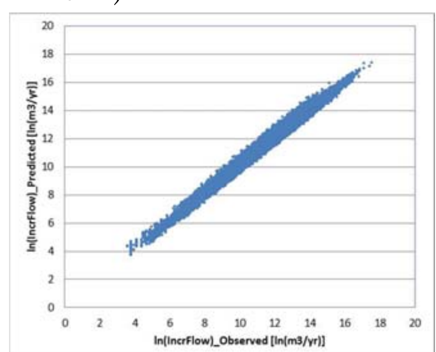
$$\ln(Q_i) = \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \beta_3 \ln(X_3) + \ldots + \sum_{k=1}^{n} \%LC_k \ln(\alpha_k) + \lambda W_i \xi_i + \varepsilon_i$$

Mean Annual Streamflow Model

- Spatial error model for the whole UMRB (whole-UMRB SEM)
- Spatial error models for three sub regions a, b, and c (sub-UMRB SEM) for twofold purposes:
  - If detailed sub-UMRB SEMs perform better than whole-UMRB SEM
  - To explore spatial variations of the coefficients in the models.

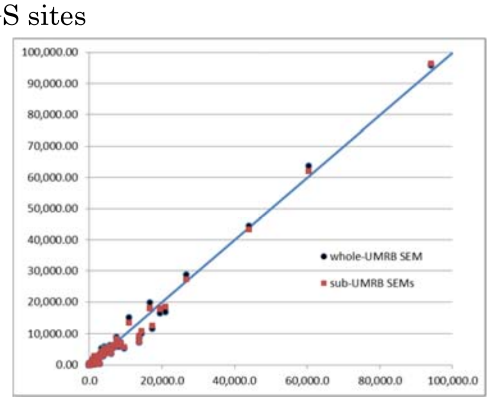
Results

- Predicted versus observed IncrFlow (in natural logarithm form)



Results

- Simulated versus observed streamflow at 533 USGS sites



Results

- Climatic & landscape coefficients

Variables	whole-UMRB SEM	sub-UMRB SEM a	sub-UMRB SEM b	sub-UMRB SEM c
lnArea	1.0050	1.0032	1.0050	1.0042
lnStreamDensity	-0.0019	-0.0028	-0.0023	-0.0032
lnPrecip	2.0391	0.8489	1.0694	2.9516
lnTemp	-0.4956	-0.1690	-0.4510	-0.7080
lnSoil	0.0060	0.0014	0.0061	0.0152
lnMaElev	-0.0965	-0.0462	-0.0996	-0.0344
lnSlope	0.0010	0.0006	0.0018	0.0005
Pseudo R-squared	0.984	0.993	0.991	0.981

Land Use

	Variables	whole-UMRB SEM	sub-UMRB SEM a	sub-UMRB SEM b	sub-UMRB SEM c
Low Intensity Residential	NLCD_21	0.0001	**0.0004**	**-0.0003**	-0.0004
High Intensity Residential	NLCD_22	**0.0002**	**0.0003**	-0.0001	0.0008
Commercial/Industrial/Transportation	NLCD_23	0.0000	**0.0004**	**-0.0003**	-0.0005
Bare Rock/Sand/Clay	NLCD_31	-0.0005	**0.0007**	**-0.0006**	0.0092
Quarries/Strip Mines/Gravel Pits	NLCD_32	**0.0005**	0.0003	0.0003	0.0004
Transitional	NLCD_33	**0.0011**	0.0009	-0.0005	**0.0016**
Deciduous Forest	NLCD_41	**0.0004**	**0.0004**	**0.0002**	**0.0004**
Evergreen Forest	NLCD_42	**0.0009**	**0.0006**	**0.0014**	**0.0005**
Mixed Forest	NLCD_43	**0.0009**	**0.0011**	**0.0010**	**0.0003**
Shrubland	NLCD_51	-0.0007	**0.0020**	**-0.2082**	**-0.0014**
Orchards/Vineyards/Other	NLCD_61	**0.0011**	0.0004	-0.0006	-
Grassland/Herbaceous	NLCD_71	**-0.0005**	**0.0003**	**-0.0012**	**-0.0004**
Pasture/Hay	NLCD_81	**0.0003**	**0.0004**	**0.0001**	**0.0002**
Row Crops	NLCD_82	**0.0001**	**0.0002**	**-0.0003**	**-0.0002**
Small Grains	NLCD_83	**0.3287**	**0.0002**	**-0.0026**	**0.0007**
Fallow	NLCD_84	0.0001	**0.1353**	-	-
Urban/Recreational Grasses	NLCD_85	**0.0006**	**0.0005**	0.0001	-0.0001
Woody Wetlands	NLCD_91	**0.0003**	**0.0001**	**0.0002**	**0.0003**
Emergent Herbaceous Wetlands	NLCD_92	0.0001	**0.0003**	-0.0001	-0.0001

Discussion

- LC is an important agent with respect to its impact on mean annual streamflow in UMRB (easy conclusion).
- LC impact on streamflow is not a simple function of a LC's spatial extent nor LC type but arguably a result of complex interactions among various LCs and climate/geomorphologic factors (modeling implication).
- Caution needs to be taken in comparing different studies or in generalization across scales regarding the impact of LC on streamflow (modeling implication).

Thank you!

Do you have any question?