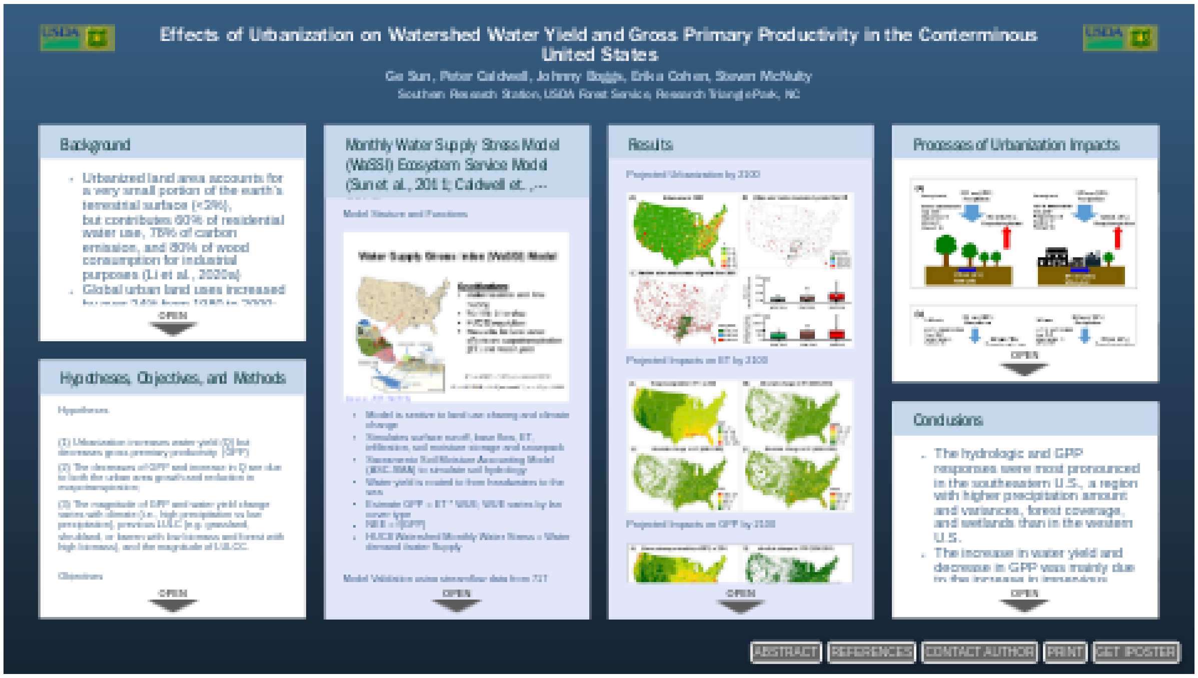
Effects of Urbanization on Watershed Water Yield and Gross Primary Productivity in the Conterminous United States



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PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

BACKGROUND

- Urbanized land area accounts for a very small portion of the earth's terrestrial surface (<3%), but contributes 60% of residential water use, 78% of carbon emission, and 80% of wood consumption for industrial purposes (Li et al., 2020a)
- Global urban land uses increased by over 34% from 1980 to 2000; projected to double by 2030, mostly in developing counties;
- World's urban population is projected to rise to 66% by 2050
- Urbanization affects water and energy cycles by removing vegetation covers (Boggs and Sun, 2011)
- Feedbacks bewteen land cover and climate exist (Urban Heat Island, Dry Island, Wet Island, Rain Island, Dirty Island; flooding and heat waves) (Hao et al., 2018).
- The role of plant evapotransiration or 'biological drange' in mitigating stormwater and flooding is underestiamted (Li et al., 2020b)

HYPOTHESES, OBJECTIVES, AND METHODS

Hypotheses

(1) Urbanization increases water yield (Q) but decreases gross premiary productvity (GPP)

(2) The decreases of GPP and increase in Q are due to both the urban area growth and reduction in evapotranspiration;

(3) The magnitude of GPP and water yield change varies with climate (i.e., high precipitation vs low precipitation), previous LULC (e.g. grassland, shrubland, or barren with low biomass and forest with high biomass), and the magnitude of LULCC.

Objectives

Quantify the resposnes of watershed water balance and GPP to projected urbanization across the US at HUC12 level in the 21st century

Methods

The WaSSI ecohydroogical model was validated and applied to projected urbanization effects on carbon and water balances at the HUC12 level in the US.

Dabases (Climate, Vegetation, Soils, Landuse change) and streamflow, and OCO2-based solar-induced chlorophyll fluorescence data for model validation

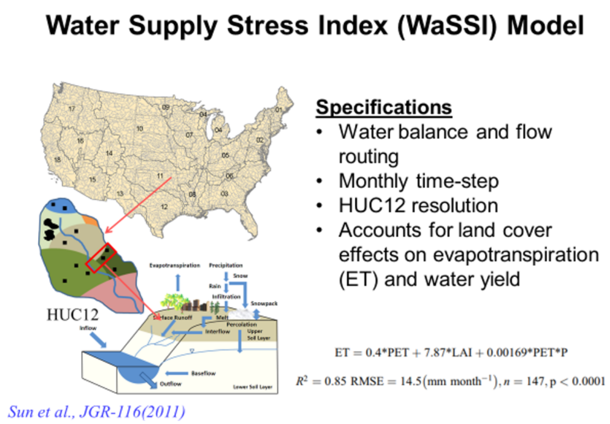
C. Li, et al. *Journal of Hydrology 583 (2020) 124581*

Table 1
Summary of databases used for WaSSI model parameterization and validation of outputs.

Data	Temporal and spatial resolution	Data sources
Land cover and land use, impervious surface	2000, 2010, 2050, 2100; 90 m × 90 m	EPA; ICLUS version 2.1 (U.S. EPA, 2017); ICLUS V2.1 uses a new spatial allocation model to calculate demand for each land use class in relation to population density. It projected land use and impervious surface products for the year 2050 and 2100 with global socioeconomic scenarios (SSPs; SSP5 scenarios chosen in this study).
Historic climate (monthly precipitation, temperature)	1961–2010; 4 km × 4 km	Parameter-elevation Regressions on Independent Slopes Model (PRISM) (http://www.prism.oregonstate.ed; Caldwell et al., 2012)
Leaf Area Index (LAI)	2000–2012; 1 km × 1 km	Moderate Resolution Imaging Spectroradiometer (MODIS) (Zhao et al., 2005)
11 Soil parameters	For SAC-SMA soil model; 1 km × 1 km	State Soil Geographic Database (STATSGO) (https://water.usgs.gov/GIS/metadata/usgswrd/XML/muid.xml
Water use efficiency (WUE) parameters	Annual by biome	Derived from eddy flux sites (Sun et al., 2011b)
Upscaled GPP product for model validation	1 km × 1 km; 8-day interval	EC-MOD GPP product for North America (Xiao et al., 2014b)
Satellite-derived solar-induced chlorophyll fluorescence for model validation of GPP	0.05° × 0.05° grid; 8-day interval	Global, OCO2- based SIF product (GOSIF) (Li and Xiao, 2019)
WaSSI model outputs: ET, water yield, and GPP	Monthly, annual	WaSSI model (Sun et al., 2011b)

MONTHLY WATER SUPPLY STRESS MODEL (WASSI) ECOSYSTEM SERVICE MODEL (SUN ET AL., 2011; CALDWELL ET. , 2012)

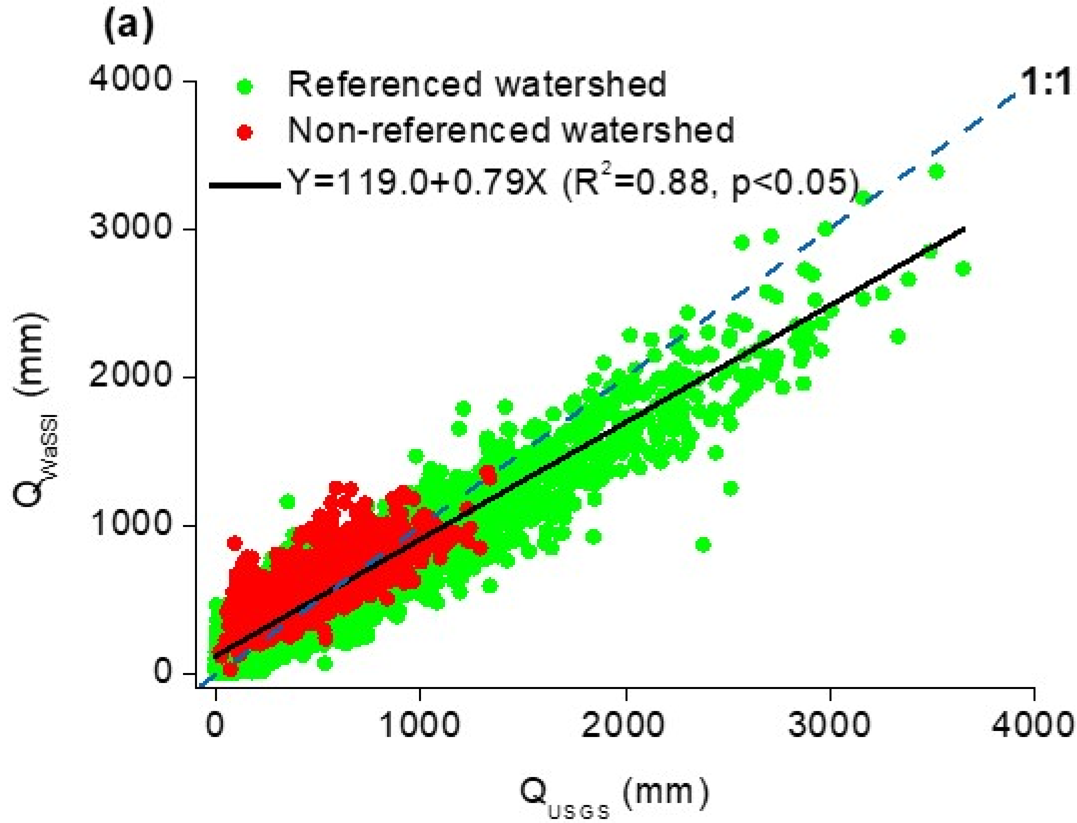
Model Struture and Functions



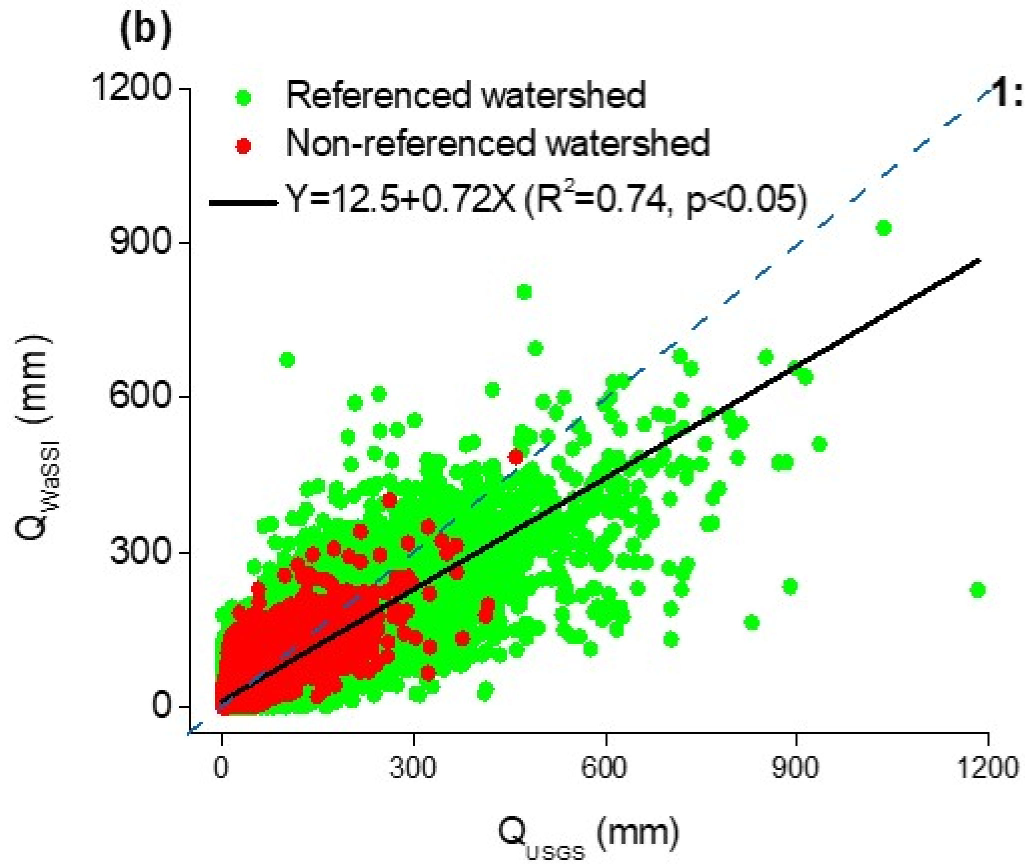
- Model is sentive to land use chaneg and climate change
- Simulates surface runoff, base flow, ET, infiltration, soil moisture storage and snowpack
- Sacramento Soil Moisture Accounting Model (ASC-SMA) to simulate soil hydrology
- Water yield is routed to from headwaters to the sea
- Esimate GPP = ET * WUE; WUE varies by lan cover type
- NEE = f(GPP)
- HUC8 Watershed Monthly Water Stress = Water demand /water Supply

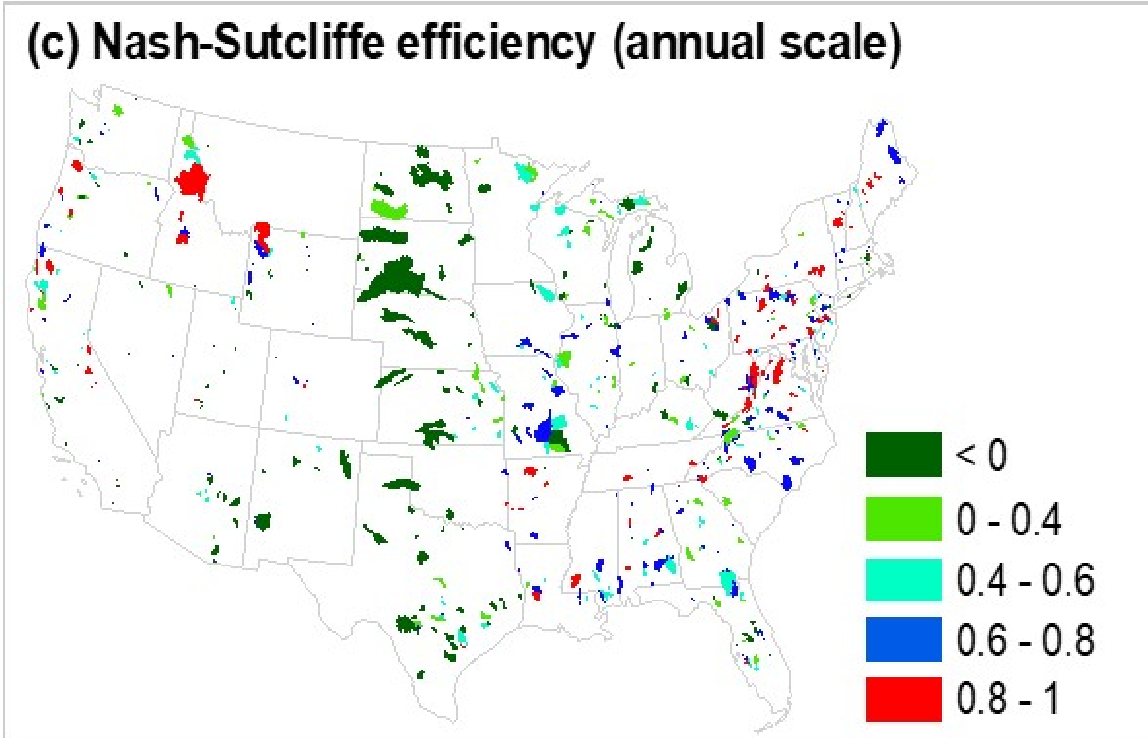
Model Validation using streamflow data from 717 gaged watersheds

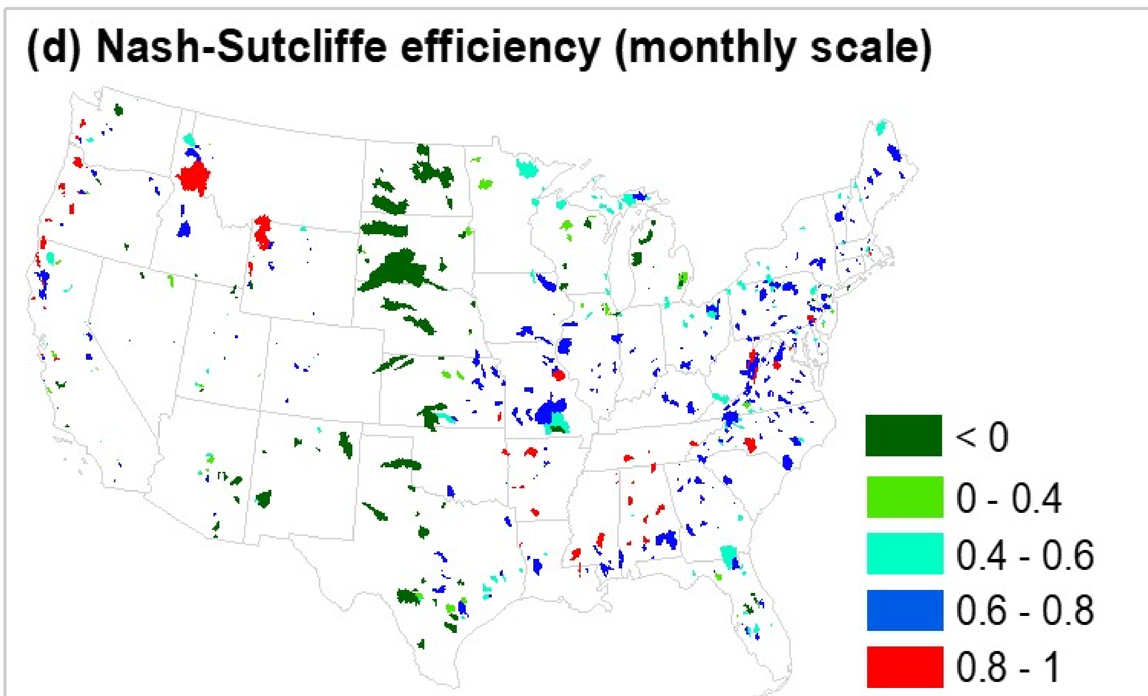
Annual scale flow validation



Monthly scale flow validation

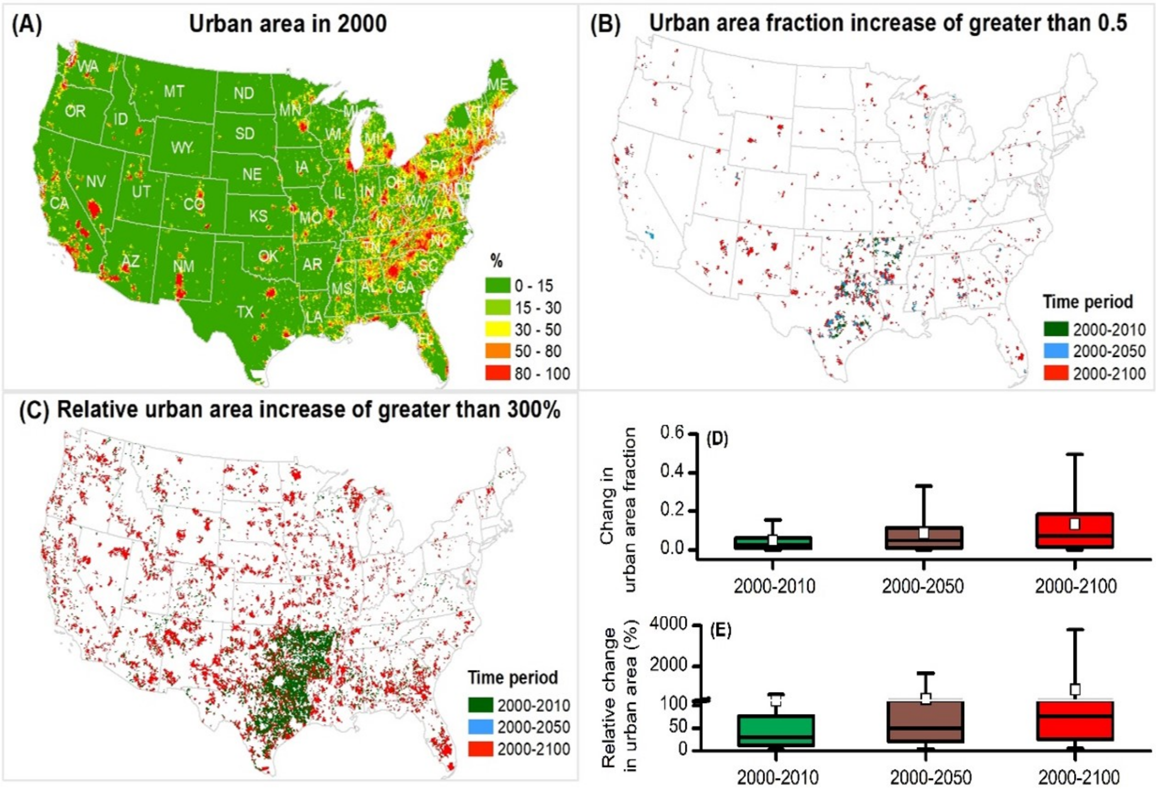



(c) Nash-Sutcliffe efficiency (annual scale)
< 0
0 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1

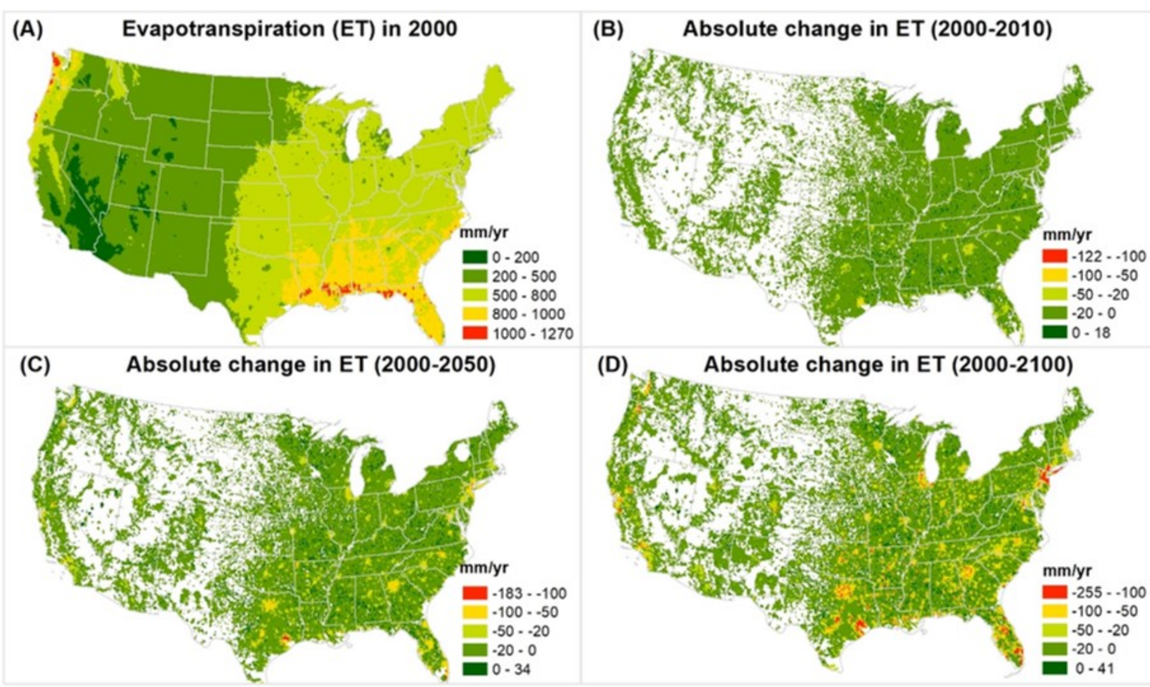

(d) Nash-Sutcliffe efficiency (monthly scale)
< 0
0 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1

RESULTS

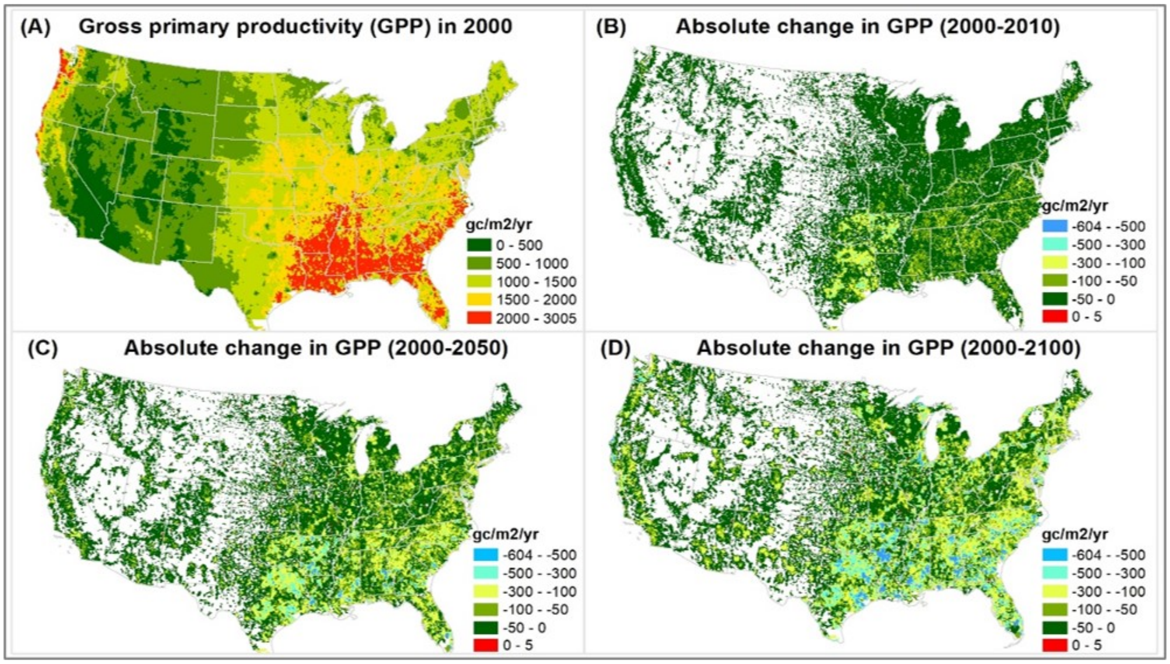
Projected Urbanization by 2100



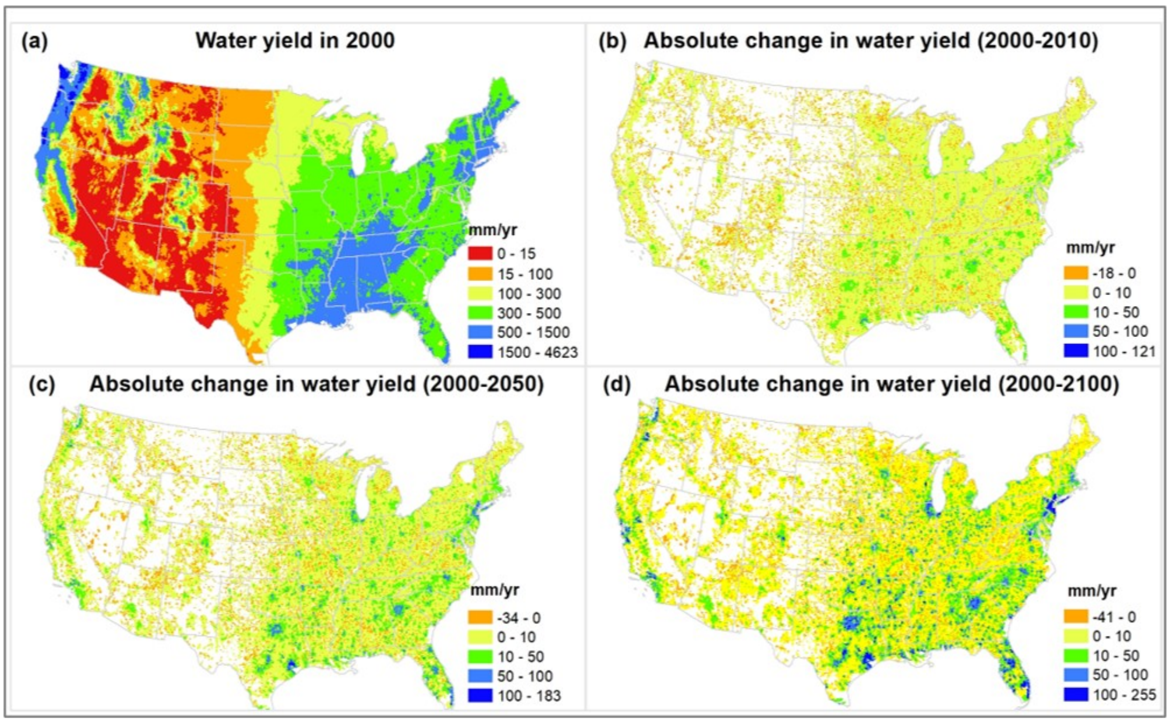
Projected Impacts on ET by 2100



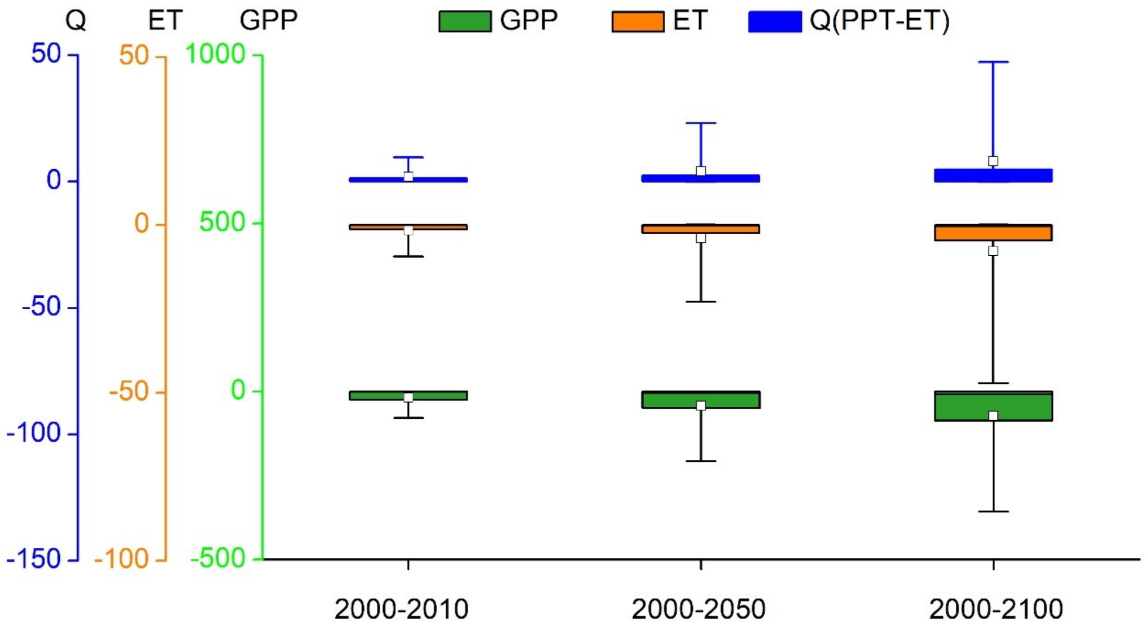
Projected Impacts on GPP by 2100



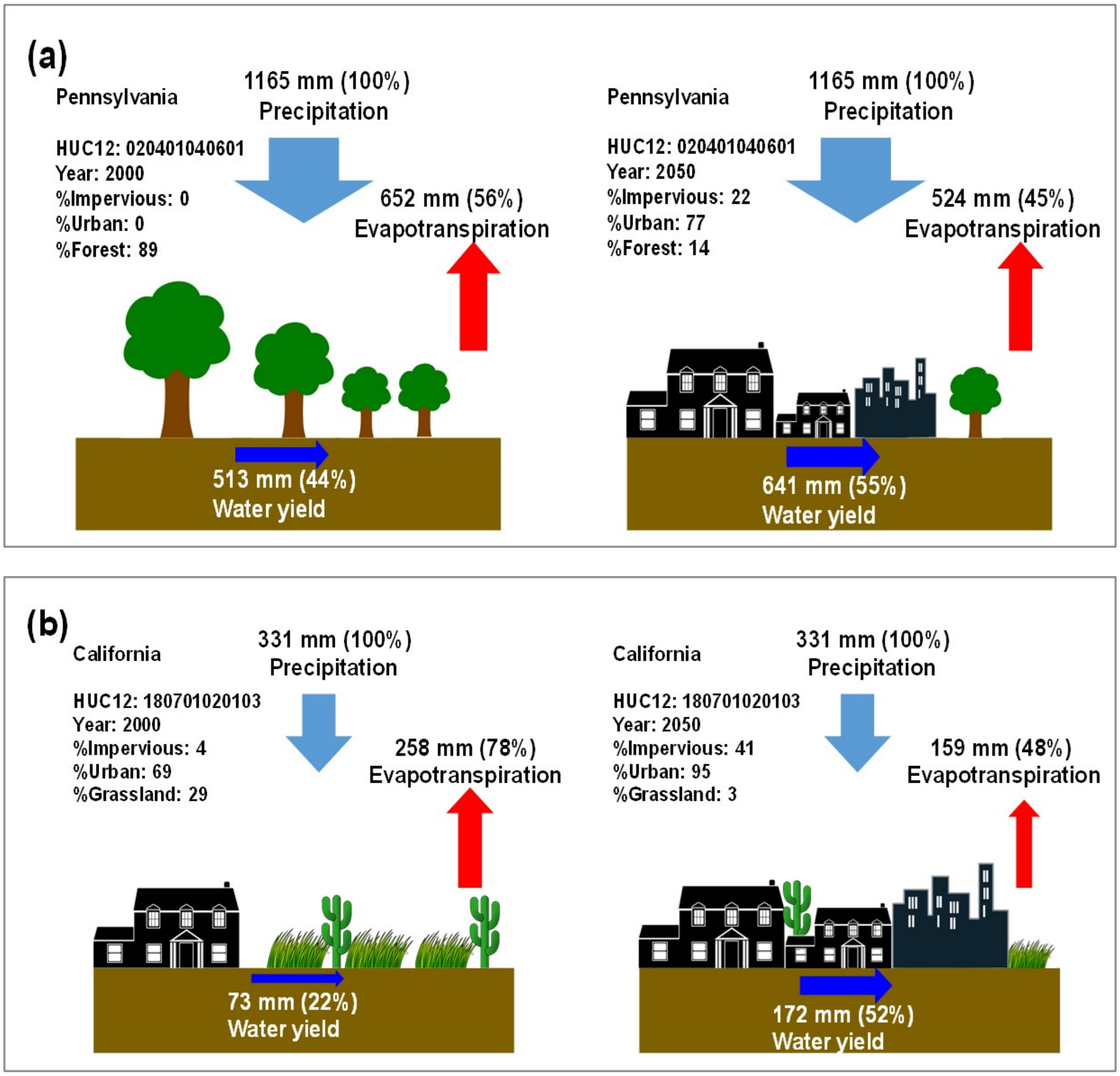
Projected Impacts on Water Yield (Q) by 2100



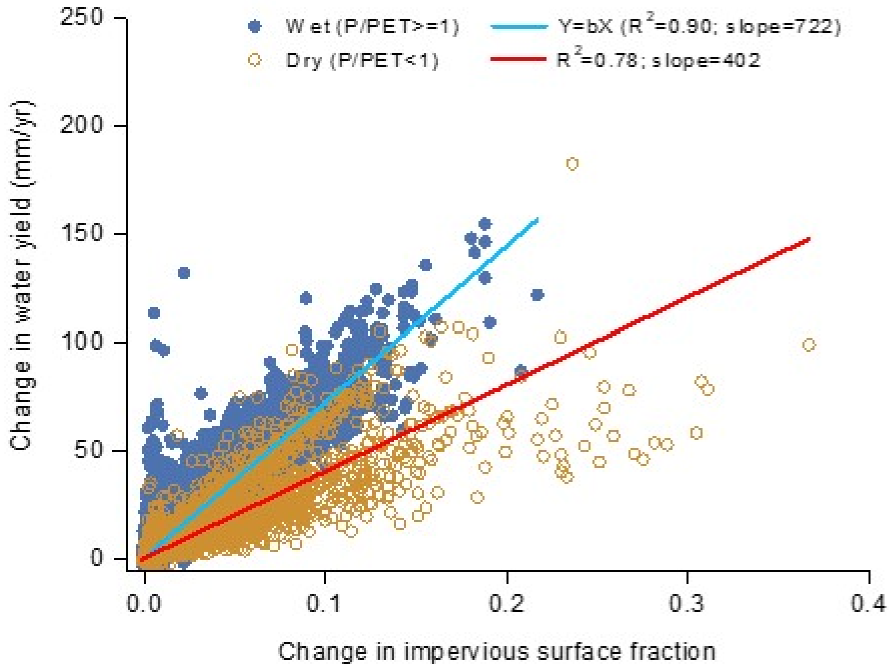
Summary: change in GPP (gC/m2/yr), ET (mm/yr), and Q (mm/yr)


Q
ET
GPP
GPP
ET
Q(PPT-ET)
50
0
-50
-100
-150
50
0
-50
-100
1000
500
0
-500
2000-2010
2000-2050
2000-2100

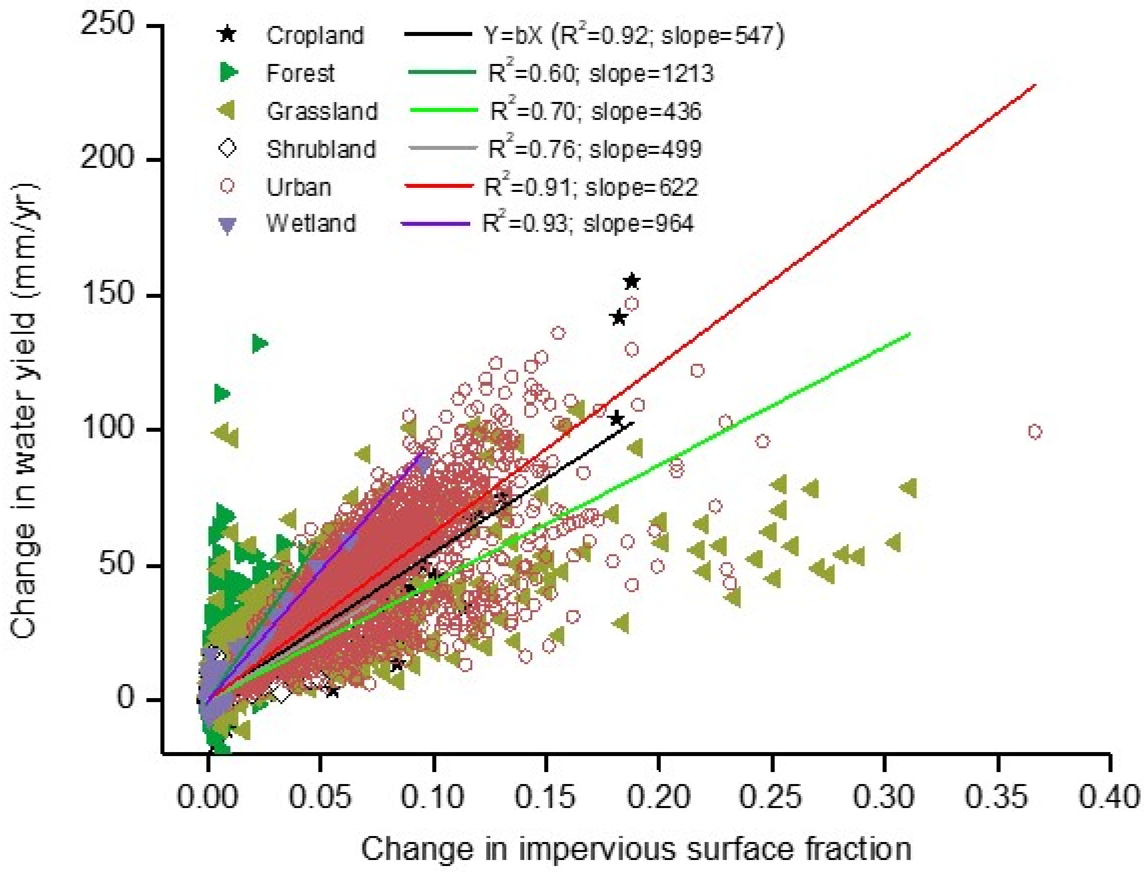
PROCESSES OF URBANIZATION IMPACTS



Hydrologic impacts vary accross climate



Hydrologic impacts vary accross origional land cover type



CONCLUSIONS

- The hydrologic and GPP responses were most pronounced in the southeastern U.S., a region with higher precipitation amount and variances, forest coverage, and wetlands than in the western U.S.
- The increase in water yield and decrease in GPP was mainly due to the increase in impervious surfaces and decrease in evapotranspiration associated with vegetation losses
- Trade-offs between watershed carbon and water fluxes under urbanization across both time and space.
- “Carbon and water impacts of urbanization are not created equal”

ABSTRACT

Urbanization represents a permanent land-use change that has great implications for watershed ecosystem functions and services. We applied an ecohydrological model (WaSSI) to evaluate the likely impacts of projected land-use change (EPA ICLUS scenarios) on water and carbon balances across the lower 48 states in the U.S. for the periods of 2000, 2010, 2050, and 2100 at a 12-digit Hydrologic Unit Code (HUC) watershed scale. We found that although the simulated impact of future urbanization on mean change in water yield (ΔQ) was small at the national level, significant changes (ΔQ >50 mm) were found in 1,046 and 3,747 watersheds by 2050 and 2100, respectively. The total CONUS Q increased from 2.03×10^6 million m^3 yr^{-1} in 2000, to 2.04×10^6 million m^3 yr^{-1} in 2010, to 2.06×10^6 million m^3 yr^{-1} in 2050, and 2.09×10^6 million m^3 yr^{-1} in 2100. Total CONUS GPP declined from 8.68 Pg C yr^{-1} in 2000, to 8.54 Pg C yr^{-1} in 2010, to 8.36 Pg C yr^{-1} in 2050, and to 8.13 Pg C yr^{-1} in 2100. Although total ΔGPP was less than 0.55 Pg yr^{-1}, or <8%, large changes (ΔGPP >300 gC^{-1} m^{-2} yr^{-1}) were found in 245, 1,984, and 5,655 of the 81,900 watersheds by 2010, 2050 and 2100, respectively. Overall, the impact of evapotranspiration, water yield, and GPP in the CONUS were influenced by background climate, previous land cover characteristics, and the magnitude and extent of land-use change. This study provides an update on the effects of urbanization on water and carbon balances in natural ecosystems. Climate change that occurs alone with projected urbanization could alter these urbanization impacts. Effective national scale watershed management strategies must consider novel combinations of local climatic and land cover conditions to minimize negative hydrologic impacts of urbanization.

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