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RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

Water Security Assessment of Current and Future Scenarios through an Integrated Modeling Framework

RUTGERS Sustainable Raritan River Initiative

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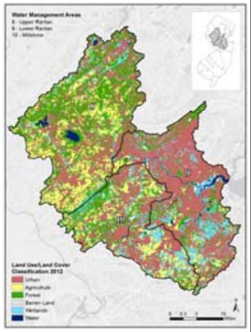
Introduction

- Freshwater is limited in quantity and it is vulnerable to human activities such as change in land use/cover, urbanization, inter basin water transfer combined with climate change.
- Raritan basin located in Central New Jersey has an increasing population trend (Giri et al., 2017) and the development trend within Raritan basin is moving especially towards Neshanic River Watershed (NRW).
- Increasing population trend combined with land use change, growing water supply demand, and climate change is going to worsen the drought condition in the NRW.



Land use/cover distribution in the RRW (source: Giri et al., 2017. Sustainable Raritan report).

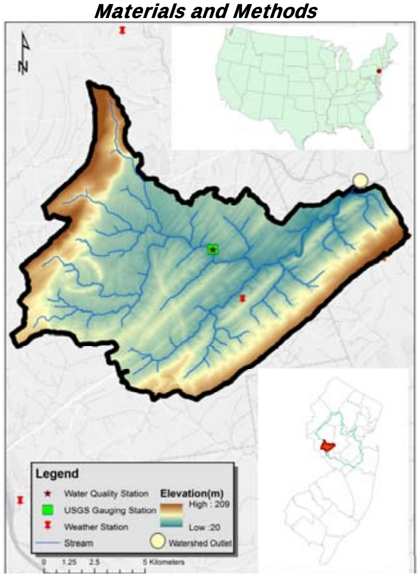
Rationale

- Blue water is the combination of surface runoff and deep aquifer recharge while green water is the summation of evapotranspiration and soil water content. Both blue and green water are directly or indirectly related to human consumption.
- Consequently, spatial and temporal distribution of blue and green water is required to identify hotspots in the watershed for an efficient water resources planning and management.
- The amount of blue water that can be withdrawn for human use must be limited to sustain downstream ecosystems. Subsequently, introduction of environmental flow requirement concept is required during water security analysis framework for maintaining a healthy river system.

Research Questions

- How does the spatial distribution of blue and green water vary across Neshanic River Watershed under current and projected land use?
- How does the water security situation potentially change under current and future land use and population?

Materials and Methods



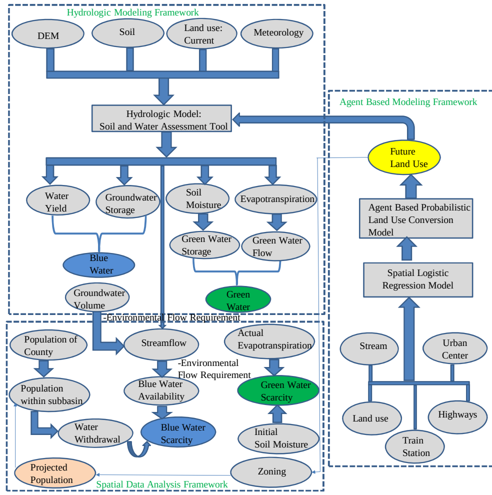
Location of Neshanic River Watershed in the study area with reference to United States and New Jersey, respectively.

Study Area

- The study area (NRW) is located in north-east part of the United States. Most parts of the watershed belongs to Hunterdon County while some parts remain inside Somerset County in Central New Jersey.
- Out of total watershed area, 39% consists of agricultural lands, 32% contains forest, 28% comprises of urban lands, and remainders are wetlands, barren land, and water.

Integrated Modeling Framework

- The integrated modeling framework for this water security study consists of three primary components: i) hydrological modeling framework, ii) agent based modeling framework, and iii) spatial data analysis framework.



Schematic of integrated modeling framework for water security analysis in Neshanic River Watershed, New Jersey.

Hydrologic Modeling Framework

- The Soil and Water Assessment Tool (SWAT), physically based spatially distributed model, was used to simulate hydrology in the study area and calculate different components of blue and green water.
- The NRW was divided into 115 subbasins and 9,291 HRUs; and a combination of 1:10:10 threshold for land use :soil: slope was provided, respectively in SWAT model
- **SWAT Model Input Data:**

Data Type	Description	Resolution	Source
Topography(raster)	Digital elevation model	3 m × 3m	NJDEP
Land use/cover (polygon)	2012-NJDEP land use	Converted to 30 m × 30 m	NJDEP
Land use/cover (raster)	The Crop Data Layer	30 m × 30 m	USDA-NASS
Soil (raster)	Soil Survey Geographic Database (SSURGO)	-	USDA-NRCS
Meteorological data	Precipitation, Temperature	Daily (mm)	NCDC
Streamflow	Discharge	Daily (m^3/Sec)	USGS
Management Practices	Tillage, fertilization, etc	-	NRCS & local farmers

Spatial Data Analysis Framework:

Water security: It is defined as " *an acceptable level of water related risks to humans and ecosystems, coupled with the availability of water of sufficient quantity and quality to support livelihoods, national security, human health, and ecosystems service*".

Water Scarcity: It is an indicator which measures the water stress level in the domain or systems. It uses the information of water demand and water availability to calculate water scarcity.

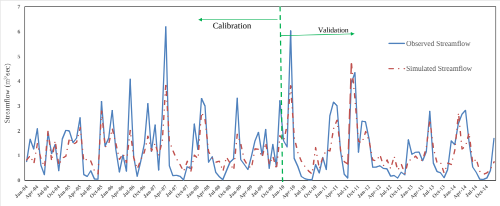
Blue Water(BW)	Green Water(GW)
Blue water flows over and under the soil surface and is stored in river, lakes, aquifers, reservoirs, and wetlands.	Green water derives from precipitation and is stored in the upper layers of the soil or vegetation and returns to atmosphere through evapotranspiration.
BW=Surface runoff + deep aquifer recharge	GW=Σ Evapotranspiration and soil water content
BW Scarcity=$\frac{BW\ requirement/withdrawal}{BW\ availability}$	GW Scarcity=$\frac{GW\ requirement/withdrawal}{GW\ availability}$
BW availability= Stremflow- Environmental flow requirement Where environmental flow requirement=0.8 × streamflow	Actual evapotranspiration=GW requirement Initial soil moisture= GW availability

Land Use Conversion through Agent Based Modeling Framework:

Spatial Logistic Regression(SLR)	Agent based Probabilistic Model(ABPM)
The logistic regression function in SLR describes as a functional relationship between land use conversion and a set of explanatory factors that influence conversion probability	ABPM is programmed in GIS environment using python and composed of actual property parcel of NRW. The agents in ABPM are forest and agricultural non-protected properties.
$Y = logit(p) = ln\left(\frac{p_k}{1-p_k}\right) = \beta_0 + \beta_1 x_{1k} + \beta_2 x_{2k} + \beta_3 x_{3k} + \beta_4 x_{4k} + \beta_5 x_{5k} + \beta_6 x_{6k}$	The model uses a Monte-Carlo process to generate the results.
Sign of the parameter indicates the direction of the influence of each explanatory variable on conversion probability	A threshold for probability cutoff points of 0.5 was used where parcels having <0.5 land use conversion were assumed non-convertible.
SLR model was validated using Receiver Operator Characteristics (ROC)	

Results and Discussion

Streamflow Calibration and Validation:



Simulated and observed monthly streamflow at USGS gauging station 01398000 in the Neshanic River Watershed.

Model evaluation parameters for streamflow in the Neshanic River Watershed.

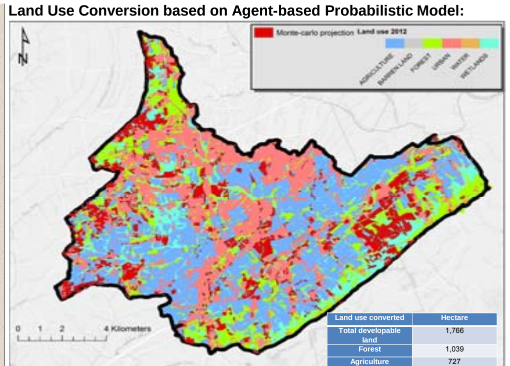
Constituent	Evaluation parameters	Overall period (2004 to 2014)	Calibration period (2004 to 2009)	Validation period (2010 to 2014)
Streamflow	NSE	0.69	0.66	0.71
	PBIAS	5.60	10.85	-1.46
	RSR	0.56	0.58	0.53

Spatial Logistic Regression:

Statistics	Value
Number of total observations	569212
Number / percentage of 0s in sampled area	556738
Number/ percentage of 1s in sampled area	12474
Chi-square (6)	3215.70 (p-value 0.00001)
-2logL0	63120.82
-2log(likelihood)	59905.12

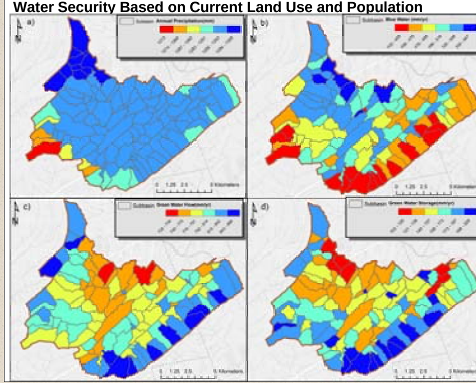
Explanatory Variables	Definition	Coefficient values
Agdist	Distance in meters to the nearest agriculture land	-0.0001
Foresdist	Distance in meters to the nearest forest land	-0.0303
Residdist	Distance in meters to the nearest residential land	0.0028
Streamdist	Distance in meters to the nearest stream	0.0062
Highwaydist	Distance in meters to the nearest highway	0.0044
Traindist	Distance in meters to the nearest train station	0.0017
Constant	-	-4.0889
ROC	-	0.7135

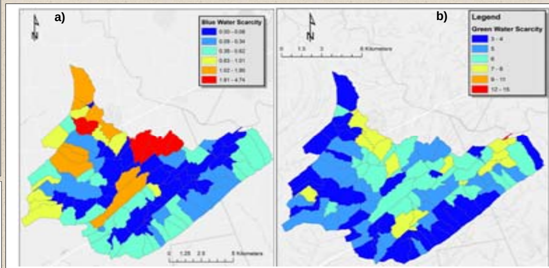
Land Use Conversion based on Agent-based Probabilistic Model:



Land use converted	Hectare
Total developable land	1,766
Forest	1,039
Agriculture	727

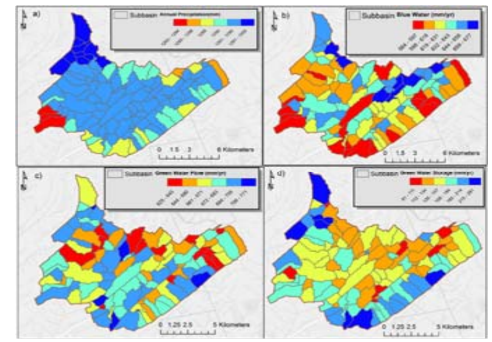
Water Security Based on Current Land Use and Population



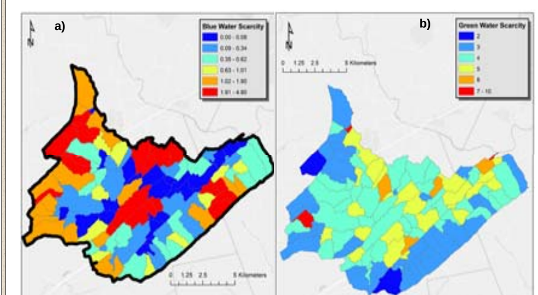


Spatial distribution of (a) blue water scarcity, (b) green water scarcity in the Neshanic River Watershed

Water Security Based on Projected Land Use and Population



Spatial distribution of (a) annual precipitation, (b) blue water, (c) green water flow, and (d) green water storage in the Neshanic River Watershed for 2022 land use conversion.



Spatial distribution of (a) blue water scarcity, (b) green water scarcity in the Neshanic River Watershed for 2022 land use conversion

Conclusions

- While no severe blue water scarcity was observed, an increasing green water scarcity was observed in some study area subbasins.
- The highest blue water scarcity were associated with higher urban land and higher water demands by residents while green water scarcity was associated with urban land use and agricultural dominated areas of lowest initial soil moisture and higher evapotranspiration.
- The agent-based probabilistic model, working at the scale of land ownership parcels, predicted that future urban development would be the result of forest, rather than farm land conversion.
- A slight increase in blue water scarcity is expected compared to current scenario due to increase in urban land as result of nearly 100% increase in population in the study area.
- Though green water flow and green water storage are expected to decrease somewhat under future condition, increasing green water scarcity was observed in only small number of study area subbasins.