SIMULATING THE HYDROLOGIC RESPONSE TO CLIMATE AND LANDSCAPE CHANGE USING THE PRECIPITATION-RUNOFF MODELING SYSTEM IN THE APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN, SOUTHEASTERN UNITED STATES

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1. ABSTRACT

The hydrologic response to statistically-downscaled general circulation model (GCM) simulations of daily surface climate and land cover (urbanization and vegetation dynamics modeling) was assessed for the Apalachicola–Chattahoochee–Flint River Basin (ACFB) for 2010–2099 as part of a series of regional assessments funded by the U.S. Geological Survey (USGS) National Climate Change and Wildlife Science Center (NCCWSC; *http://nccwsc.usgs.gov/*). To provide integrated science that is useful to resource managers in understanding the effects of climate and land-cover change on a range of ecosystem responses, this study (the Southeast Regional Assessment Project) links simulation models that span a broad range of scales and disciplines; from planetary GCMs to local models of landscape dynamics and biota (fig. 1). As part of the Southeast Regional Assessment Project (Dalton and Jones, 2010; *http://serap.er.usgs.gov/*), the first regional assessment funded by NCCWSC, scientists have developed regional models (climate, land cover, hydrologic, and ecological) to simulate hydrologic and ecological response of the ACFB (a 50,000 square kilometer basin located in the southeastern United States) to potential changes in climate and land cover (fig. 2). Three GCM simulations for two carbon emissions scenarios (A1Fi (high) and B1 (low)) (Table 1) from phase 3 of the World Climate Research Programme's Coupled Model Intercomparison Project (Intergovernmental Panel on Climate Change, 2007) were statistically downscaled, using an asynchronous regional regression model (Stoner et al., 2012), to 1/8° grids of daily precipitation and minimum and maximum air temperature developed by Maurer et al. (2002).

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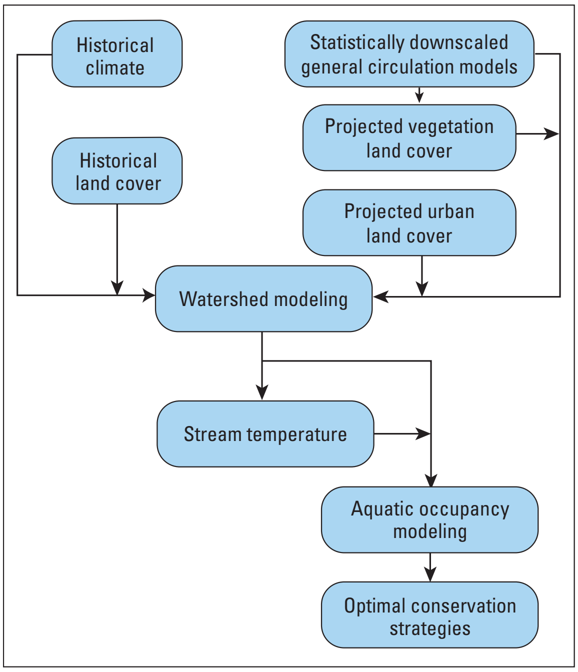

Figure 1. Diagram of Southeast Regional Assessment Project data flow showing the various linkages of climate, landscape, and biota dynamics to watershed modeling.

The statistically-downscaled climate data sets were used as input to the Precipitation-Runoff Modeling System (PRMS), a deterministic, distributed-parameter, physical-process based watershed model used to simulate and evaluate the effects of various combinations of climate and land cover on watershed response (Leavesley et al., 1983; Leavesley et al., 2005; Markstrom et al, 2008). For this application of PRMS, the ACFB was divided into 258 hydrologic response units (fig. 3) in which the components of flow (groundwater, shallow subsurface, and surface runoff) are computed in response to climate, land surface, canopy, and subsurface characteristics of the basin. Additional details of the construction and calibration of the ACFB PRMS model are documented by LaFontaine et al. (2013). Projections of

Table 1. Climate inputs used in Precipitation-Runoff Modeling System hydrologic simulations. General Circulation models and carbon emissions scenarios are from phase 3 of the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP3).

Climate input	Scenario	Time period	Source
Historical observations	Historical	1950–1999	Gridded observations of meteorological data (Maurer et al., 2002)
CCSM3	A1Fi	1960–2099	National Center for Atmospheric Research, Community Climate Systems Model, version 3
CCSM3	B1	1960–2099	National Center for Atmospheric Research, Community Climate Systems Model, version 3
GFDL	A1Fi	1960–2099	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, version 2.1
GFDL	B1	1960–2099	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, version 2.1
PCM	A1Fi	1960–2099	National Center for Atmospheric Research, Parallel Climate Model, version 1
PCM	B1	1960–2099	National Center for Atmospheric Research, Parallel Climate Model, version 1

urbanization from the Slope, Land use, Exclusion, Transportation, and Hillshade (SLEUTH; Clarke and Gaydos, 1998) model and projections of vegetation from the Vegetation Dynamics Development Tool and Tool for Exploratory Landscape Scenario Analyses (VDDT-TELSA; ESSA Technologies Ltd.) were used as inputs to PRMS to simulate projected land-cover impacts on hydrologic response. This study also analyzed a combination of historical climate with projected land cover to determine the required amount of additional surface-depression storage capacity needed to offset increases in surface runoff because of land-cover change. Projections of increased surface-depression storage capacity were included to simulate effects of best management practices to mitigate flow regime change due to urbanization as current building practices generally require runoff mitigation features (often detention ponds) to be constructed to capture and delay increases of rapid surface runoff from constructed impervious surfaces such as buildings and pavement.

Three cases were studied to assess the hydrologic response of the ACFB to climate and land-cover change for each GCM simulation and carbon emissions scenario combination: (1) climate change only (CO), (2) climate and land-cover change (C+L), and (3) climate and land-cover change with additional surface-depression storage capacity (C+L+S). The climate and hydrology for 20-year windows centered on years 2030, 2060, and 2090 were compared to historical conditions (1990–2009). For hydrologic studies that include projections of land-cover change (urbanization in particular), any analysis of runoff beyond the change in total runoff (such as analysis of extreme high or low flows) should include effects of stormwater management practices as these features may affect flow timing and magnitude and results without them may be misleading. Potential changes in water availability and how biota may respond to changes in flow regime in response to climate and land-cover change may prove challenging for managers attempting to balance the needs of future development and the environment.

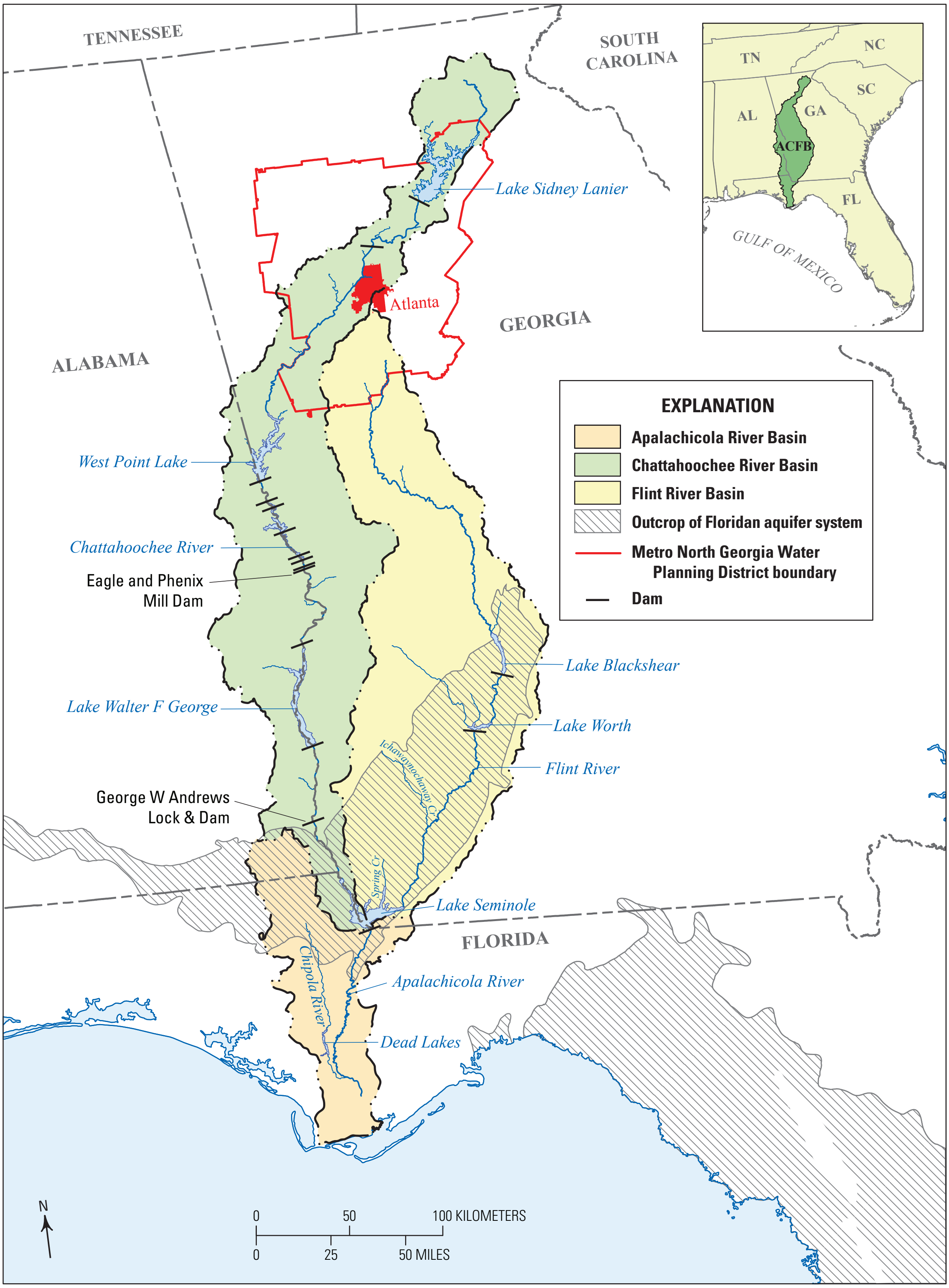

Figure 2. ***Location of the Apalachicola–Chattahoochee–Flint River Basin (ACFB). [MNGWPD, Metro North Georgia Water Planning District]***

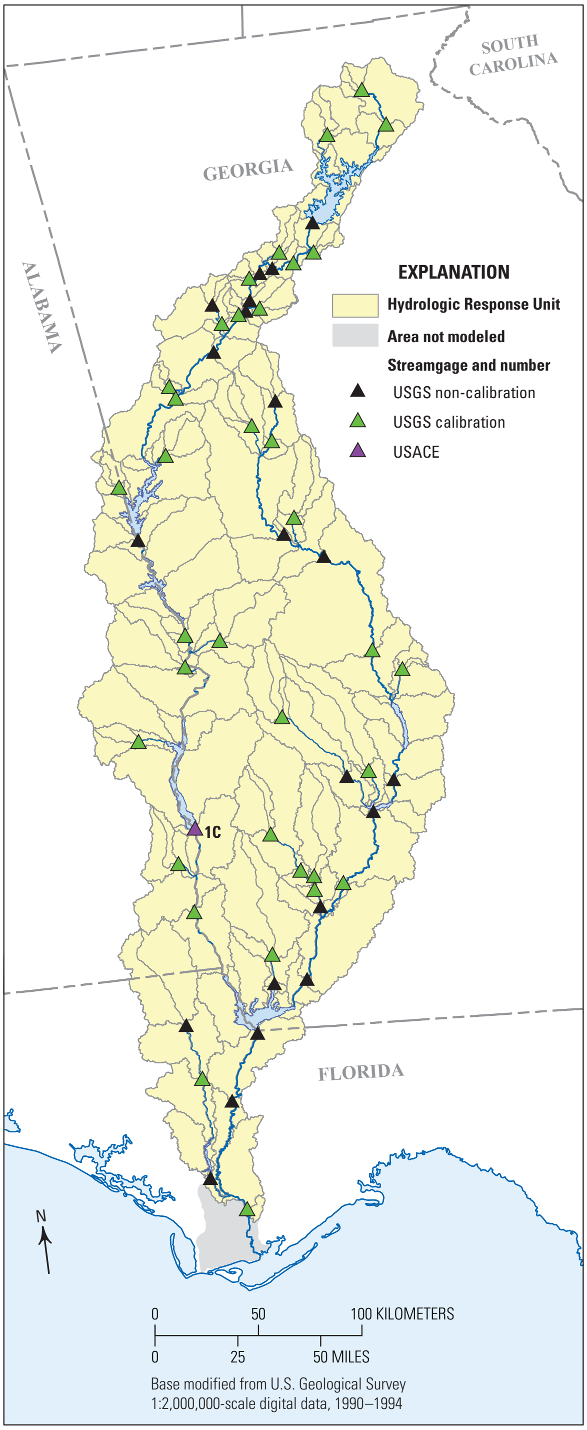

Figure 3. Location of Precipitation-Runoff Modeling System hydrologic response units (HRUs), stream network, and U.S. Geological Survey (USGS) streamgages. [USACE, U.S. Army Corps of Engineers]

2. REFERENCES

Clarke, K.C., L. Gaydos, 1998: Long term urban growth prediction using a cellular automaton model and GIS—Applications in San Francisco and Washington/Baltimore. International Journal of Geographical Information Science.

Dalton, M.S., S.A. Jones, comps., 2010: Southeast Regional Assessment Project for the National Climate Change and Wildlife Science Center. U.S. Geological Survey Open-File Report 2010–1213, 38 p.

Intergovernmental Panel on Climate Change, 2007: Summary for policymakers, in Climate change 2007—The physical science basis, contributions of working group 1 to the fourth assessment report of the Intergovernmental Panel on Climate Change: Cambridge and New York, Cambridge University Press, 18 p.

LaFontaine, J.H., L.E. Hay, R.J. Viger, S.L. Markstrom, R.S. Regan, C.M. Elliott, J.W. Jones, 2013: Application of the Precipitation-Runoff Modeling System (PRMS) in the Apalachicola–Chattahoochee–Flint River Basin in the southeastern United States. U.S. Geological Survey Scientific Investigations Report 2013–5162, 118 p.

Leavesley, G.H., R.W. Lichty, B.M. Troutman, L.G. Saindon, 1983: Precipitation-runoff modeling system-User's manual. U.S. Geological Survey Water-Resources Investigations Report 83–4238, 207 p.

Leavesley, G.H., S.L. Markstrom, R.J. Viger, L.E. Hay, 2005: USGS Modular Modeling System (MMS)—Precipitation-Runoff Modeling System (PRMS) MMS-PRMS. In Singh, V.P., and D.K. Frevert, eds., Watershed Models: Boca Raton, FL, CRC Press, p. 159–177.

Markstrom, S.L., R.G. Niswonger, R.S. Regan, D.E. Prudic, P.M. Barlow, 2008: GSFLOW—Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005). U.S. Geological Survey Techniques and Methods 6-D1, 240 p.

Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, 2002: A long-term hydrologically based dataset of land surface fluxes and states for the conterminous United States. Journal of Climate, 15, p. 3237-3251.

Stoner, A.M.K., K. Hayhoe, X. Yang, D.J. Wuebbles, 2012: An asynchronous regional regression model for statistical downscaling of daily climate variables. International Journal of Climatology. DOI: 10.1002/joc.3603.