Rainfall is Changing in Frequency, Magnitude, and Intensity: Implications for Stormwater Management

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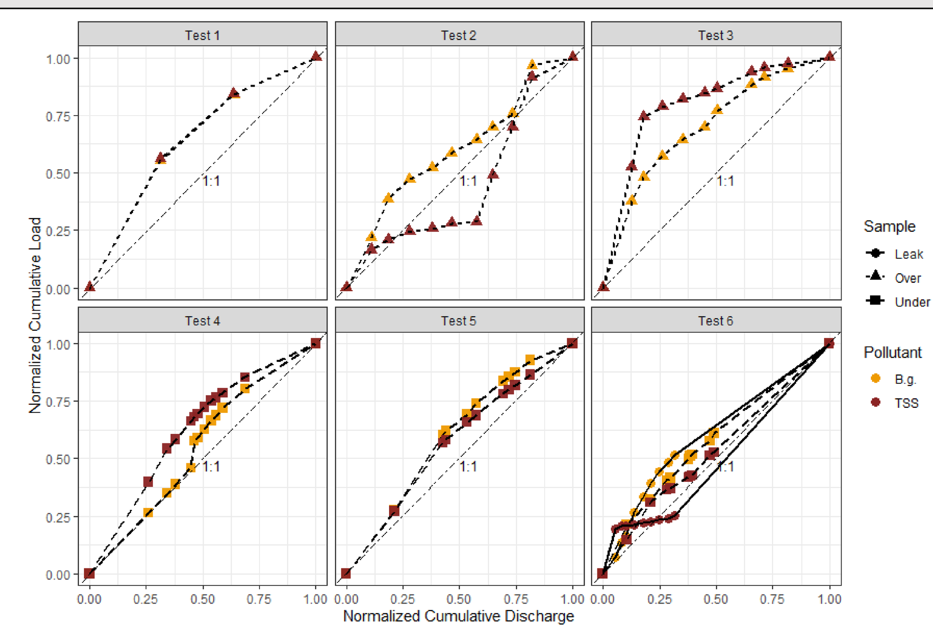
Background

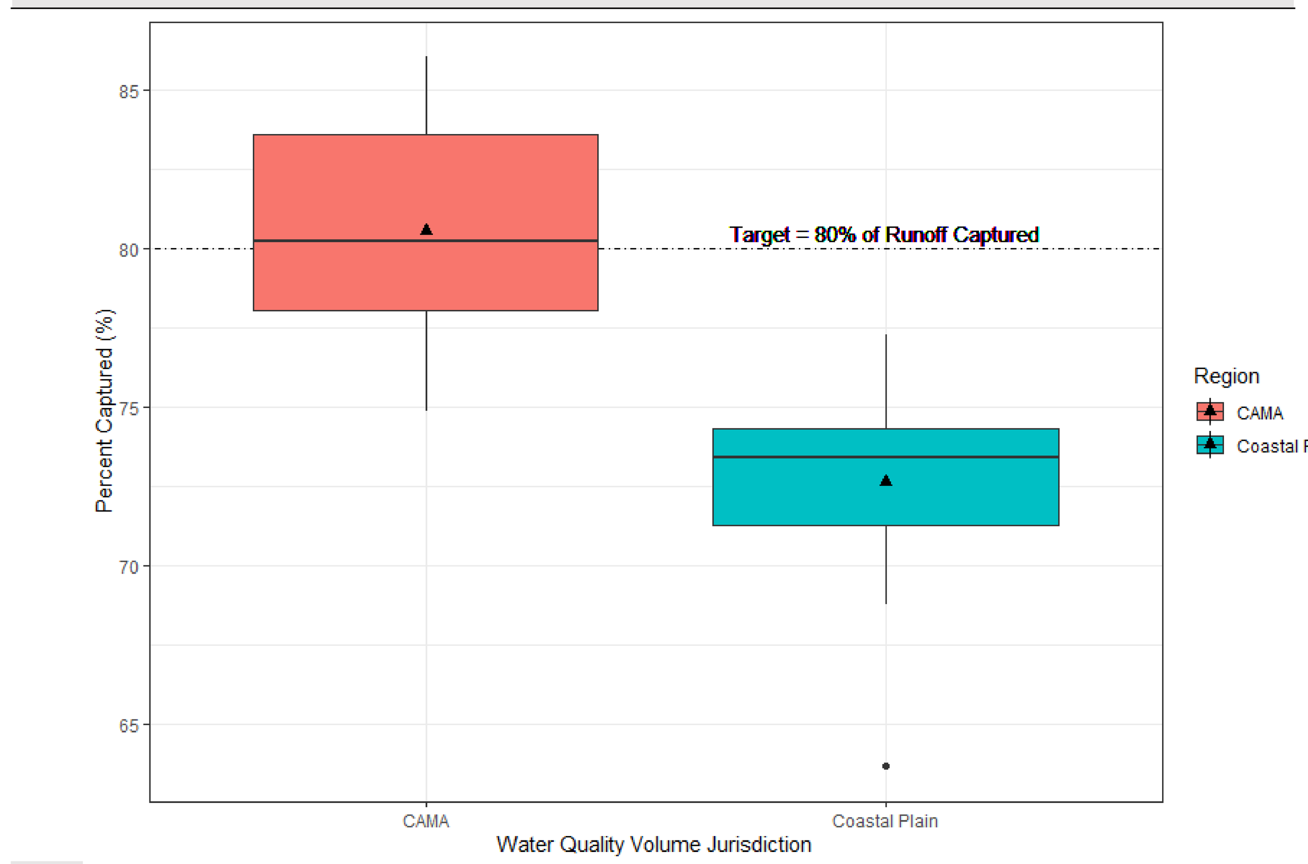
Impervious surfaces like roofs and roads increase stormwater runoff. In many cases, most pollutants are washed off hardscapes during the first portion of runoff. This phenomenon is called the first flush because nearly all the mass (80%) is delivered during the initial volume (30%) of runoff (Bertrand-Krajewski et al., 1998). Stormwater control measures (SCMs) are one tool to reduce the deleterious impacts of urban runoff. However, current design guidance, such as the volume of runoff required to be treated, is based upon historical rainfall records.



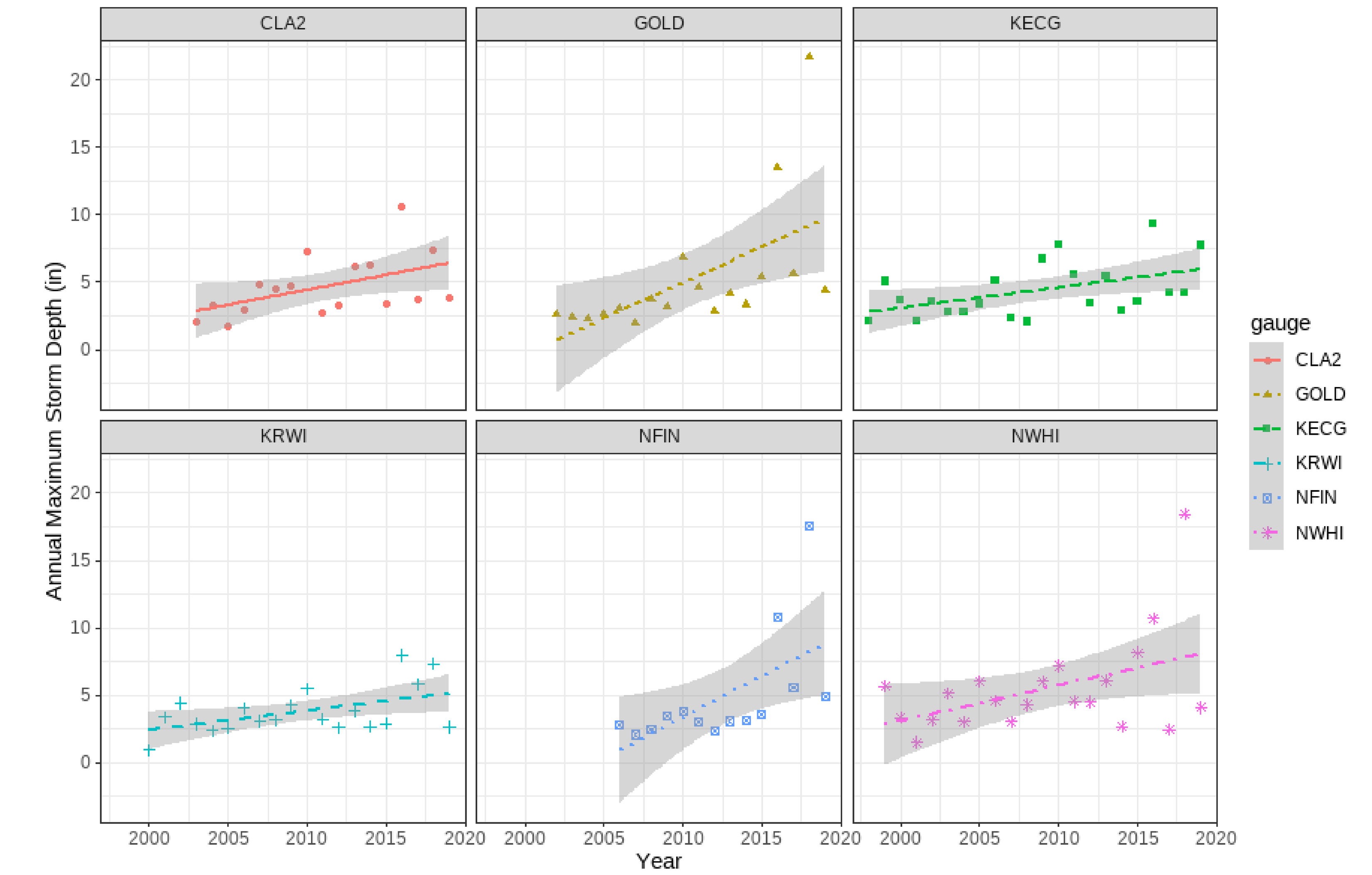
Determination of the volume of runoff that needs to be treated requires setting a threshold. Often, this threshold attempts to optimize for land availability and achieving enough water treatment. In North Carolina, enough water treatment is assumed to occur if an SCM can capture 80 to 90% of the annual stormwater runoff. In light of the first flush phenomenon, this should be enough storage to capture and treat nearly all pollutants.

Bean (2005) determined the rainfall depths associated with capturing 10 to 90% of all rainfall from 1974 to 2003 for nine cities in North Carolina. This guidance still applies today in the form of the water quality event. For most of North Carolina, this equates to capturing the 1-inch event. For Coastal Area Management Act (CAMA) Counties, this equates to capturing the 1.5-inch rainfall.

Percent Captured from 1995 to 2020



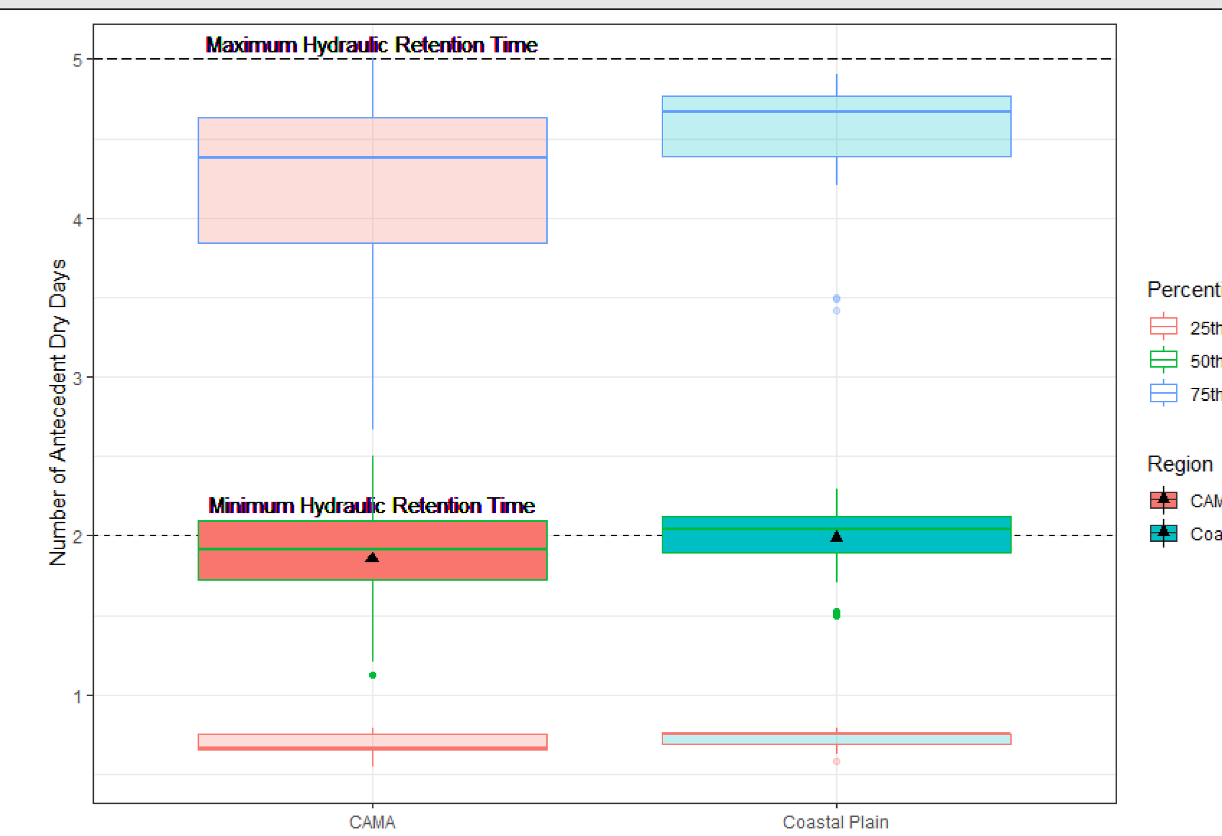
Nonstationary Annual Maximum



Current Design Guidance

City	90 cm (in)	85 cm (in)	80 cm (in)	70 cm (in)	60 cm (in)	50 cm (in)	40 cm (in)	30 cm (in)	20 cm (in)	10 cm (in)
Percent Event Depth for the Period of 1974 to 2003										
Piedmont/Mountains										
Asheville	3.3 (1.3)	2.6 (1.0)	2.1 (0.8)	1.5 (0.6)	1.1 (0.4)	0.8 (0.3)	0.6 (0.2)	0.4 (0.1)	0.2 (0.1)	0.1 (0.0)
Brevard	3.9 (1.6)	3.3 (1.3)	2.8 (1.1)	2 (0.8)	1.5 (0.6)	1.1 (0.4)	0.8 (0.3)	0.5 (0.2)	0.3 (0.1)	0.1 (0.1)
Charlotte	4.1 (1.6)	3.3 (1.3)	2.7 (1.1)	1.9 (0.8)	1.4 (0.6)	1 (0.4)	0.7 (0.3)	0.5 (0.2)	0.3 (0.1)	0.1 (0.1)
Greensboro	4.0 (1.6)	3.1 (1.2)	2.6 (1.0)	1.9 (0.7)	1.4 (0.5)	1 (0.4)	0.7 (0.3)	0.5 (0.2)	0.3 (0.1)	0.1 (0.0)
Raleigh	3.7 (1.4)	2.9 (1.2)	2.5 (1.0)	1.8 (0.7)	1.3 (0.5)	1 (0.4)	0.7 (0.3)	0.5 (0.2)	0.3 (0.1)	0.1 (0.0)
Coastal Plain										
Elizabeth City	4.1 (1.6)	3.1 (1.2)	2.6 (1.0)	1.8 (0.7)	1.3 (0.5)	0.9 (0.4)	0.7 (0.3)	0.4 (0.2)	0.3 (0.1)	0.1 (0.0)
Fayetteville	3.9 (1.5)	3.2 (1.2)	2.6 (1.0)	1.9 (0.7)	1.4 (0.5)	1 (0.4)	0.7 (0.3)	0.5 (0.2)	0.3 (0.1)	0.1 (0.1)
Greenville	4.7 (1.9)	3.6 (1.4)	2.9 (1.1)	2 (0.8)	1.5 (0.6)	1.1 (0.4)	0.8 (0.3)	0.5 (0.2)	0.3 (0.1)	0.1 (0.1)
Wilmington	5.7 (2.2)	4.4 (1.7)	3.6 (1.4)	2.5 (1.0)	1.8 (0.7)	1.3 (0.5)	0.9 (0.4)	0.6 (0.2)	0.4 (0.1)	0.2 (0.1)

Frequency of Storms from 1995 to 2020



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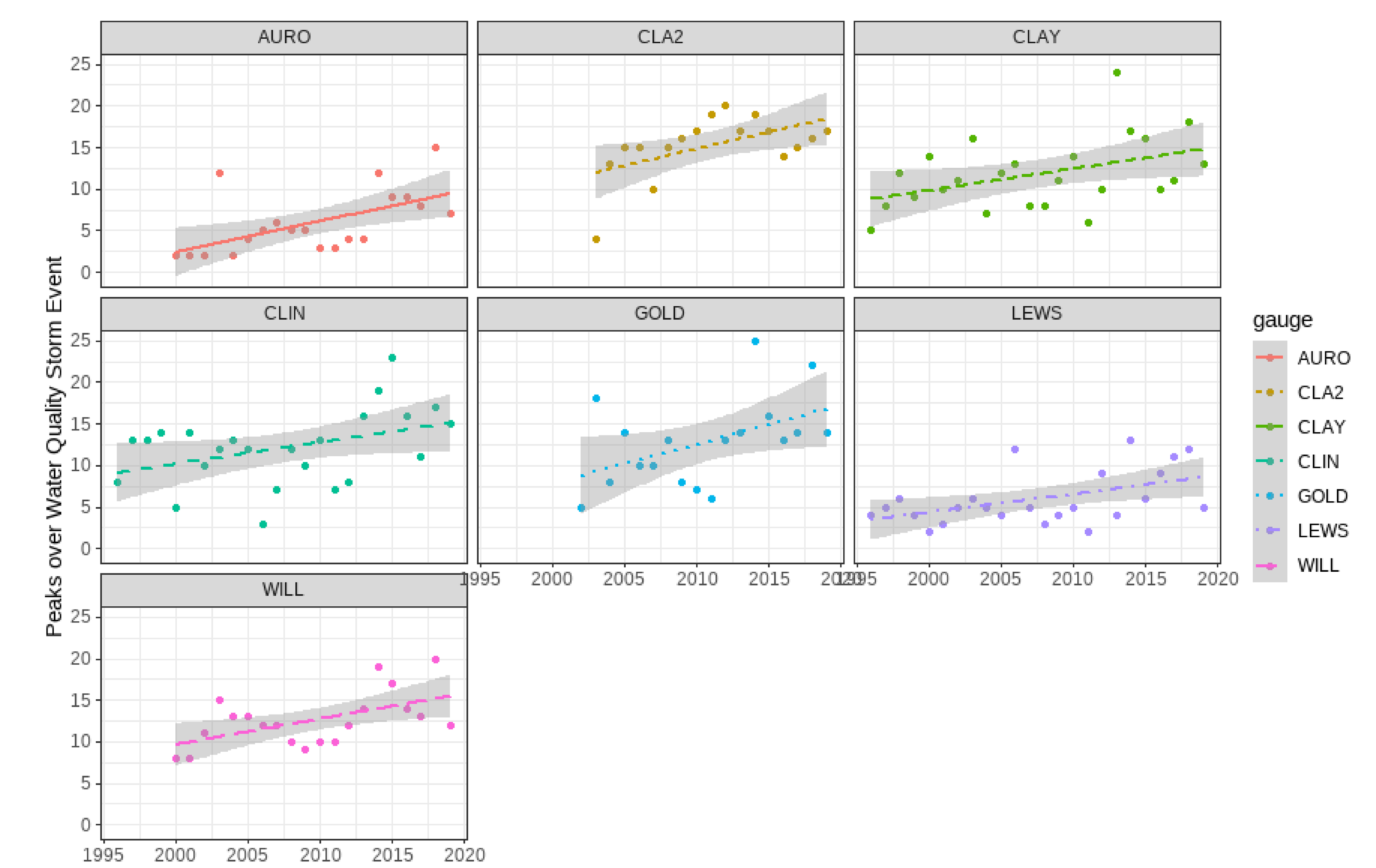
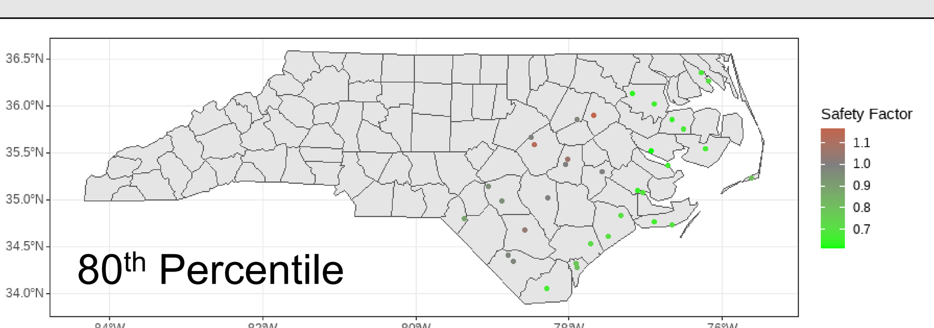
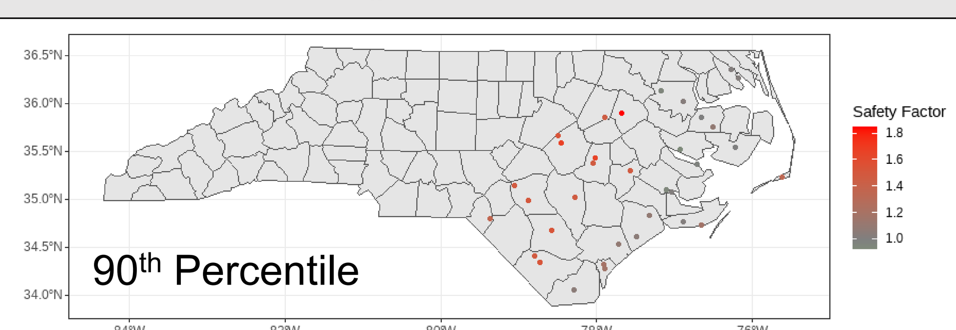
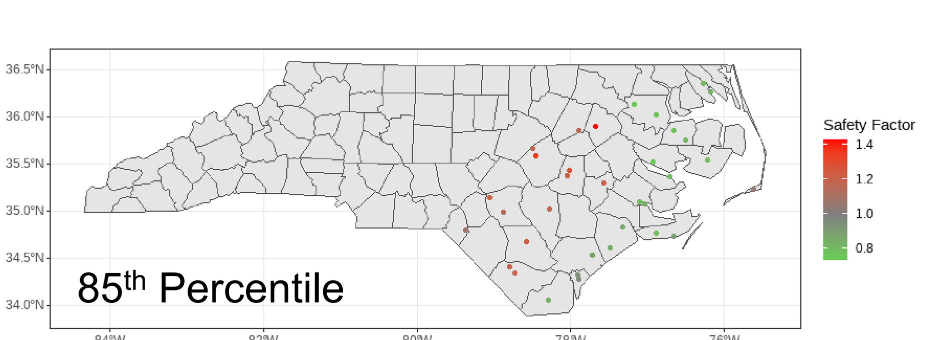
Nonstationary Peak Storm Frequency



90th Percentile Rainfall Depth Factor of Safety



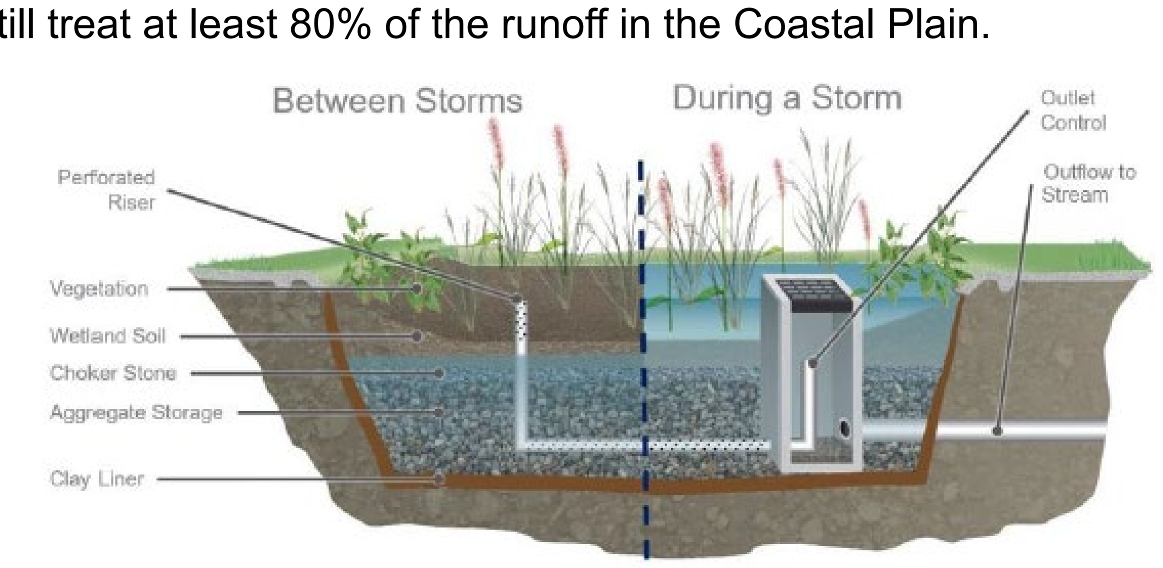




Although current design guidance is not based on percentile storms, it is one useful metric for SCM designers. For the 80th to 90th percentile, the CAMA counties 1.5-inch water quality volume is robust to historical rainfall while Coastal Plain counties require factors of safety from 1.1 to 1.8.

Conclusions and Future Design Guidance

Ancillary research suggests that designs which incorporate subsurface water storage, vegetation, and modified outlet structures will be the most resilient adaptation to a changing climate. Both manual and automated pre-flood drawdown will increase stormwater storage. Ultimately, SCM footprint, hydraulic conductivity, and ponding depth need to increase by a factor of 1.1 to 1.6 to still treat at least 80% of the runoff in the Coastal Plain.



Location (Station)	County	Period of Record	90% Storm cm (in)	80% Storm cm (in)
Wilmington (KILM)	New Hanover	1996-2020	8.1 (3.2)	5.8 (2.3)
Varnamtown (NNAC)	Brunswick	2000-2020	9.8 (3.8)	6.1 (2.4)
River Road (NBFT)	Beaufort	2003-2020	6.0 (2.4)	3.3 (1.3)
Whiteville (WHIT)	Columbus	1996-2020	8.9 (3.5)	6.3 (2.5)
Maxton (KMEB)	Scotland	1998-2020	4.5 (1.8)	3.5 (1.4)
Fayetteville (KFAY)	Cumberland	1998-2020	5.4 (2.1)	4.1 (1.6)
Hatteras (KHSE)	Dare	1996-2020	6.4 (2.5)	5.0 (2.0)
Elizabeth City (KECG)	Pasquotank	1998-2020	4.8 (1.9)	3.0 (1.2)