Examining Runoff Predictions under Climate Change

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Introduction

Introduction

Predicting the weather may seem futile but is necessary. By modeling when, where, and how big a storm will be, we can ensure that the structures we build and the people that rely on them can be as safe as possible. To predict the weather, we must make assumptions, and after we make a model, we can see if our assumptions within the model bear accurate predictions.

Objectives

The model we are examining is the NRCS Curve Number Method. This method for deriving runoff was constructed with before the concept of global scale climate change, so we must see if the assumptions previously made still hold up in a constantly changing environment.

Method

Data Collection

Unlike NOAA Atlas 14 that returns rainfall only from return periods, the newly released NOAA Atlas 15 additionally provides precipitation predictions based on Global Temperature Increases. Python code was written to collect 60,000 data points in a grid for further analysis, from temperature increases from 1.5 to 5 degrees Celsius.

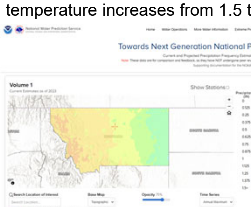

Figure 1(a)

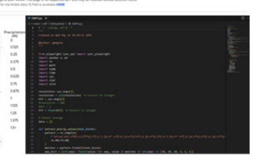

Figure 1(b)

Runoff Calculations

Geography, or more specifically soil type, matters when calculating runoff (Q). The more impervious the soil, the more runoff, and the more permeable the soil, the more storage (S), and greater the Initial abstraction (Ia).

Table 1(a) – Curve Number Table

Curve Number Table		
WaterShed Type	CN	HIGH
Pavement	98	RUNOFF
Developed Land	81	
Montana (assumed)	75	
Crop Farm	67	
Forest	45	
Wetland	30	LOW RUNOFF

Table 1(b) is an example worked out with the NRCS curve number (CN) method, one with a high rainfall event and the other low. With low rainfall events, the Initial abstraction for λ=0.2 consumes most of the precipitation in the numerator, leading to extremely low runoff predictions when compared to λ=0.05. This would put the 1in rainfall event into Zone 1, and conversely the 6in event into Zone 3.

Background

Return Periods

You might've heard the term "100-year storm" in relation to a large rainfall event. This just means a storm capable of producing that level of rainfall has a 1% chance of happening within the next year. Although it's possible to have 2 of these 100-year storms back-to-back, its extremely unlikely. It seems like a lot of these storms have been happening lately, are we just unlucky, or are probability of these events occurring shifting against our favor?

Hydrologic Conservatism

An example of an assumption made within the NRCS method is the Initial Abstraction ratio, lambda (λ). The assumption is that 20% of the storage a watershed holds (λ=0.2) immediately consumes rainfall, and that fixed volume of water doesn't become runoff. However, some hydrologists observed runoff when the NRCS model predicted none, and when they changed the lambda value to 0.05, it better represented certain storm events. So, which do we choose?

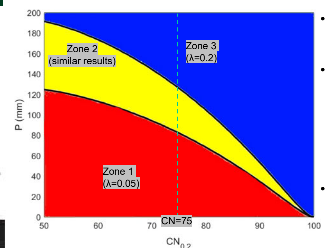

Figure 2(a) – Zone map with variable CN

- Both lambda values can yield higher runoff results
- We calculate runoff using both and choose the lambda that yields the higher result for that specific case, as an additional FOS, as seen in Table 1(b).
- The runoff formula applies only if P > Ia, which causes problems for small rainfall events with λ=0.2

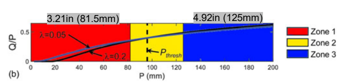

Figure 2(b) – Preferable Lambda for CN = 75, Green line on 2(a)

Zones

Besides denoting what lambda value is preferable in the NRCS model for a specific rainfall event, breaking up rainfall into 3 Zones makes the data more easily interpretable. Zone 1 are events with less than 3.21 inches of rain, Zone 3 with events over 4.92 inches, and Zone 2 as the in-between zone.

Table 1(b) – Example of Zone Calculation and Lambda Selection using Conservatism

Why do we use different Initial Abstraction Ratios?			
	Formulas	P=1in	P=6in
CN(0.2)	$CN_{0.05} = 1.28CN_{0.2} - 28.4$	75	75
CN(0.05)		67.6	67.6
S(0.2)	$S = \left(\frac{1000}{CN} - 10\right)$	3.333	3.333
S(0.05)		4.793	4.793
Ia (0.2)	$I_a = \lambda S$	0.667	0.667
Ia (0.05)		0.240	0.240
Q (0.2)	$Q = \frac{(P - I_a)^2}{P + S - I_a}$	0.030	7.758
Q (0.05)		0.104	5.975

Collected Data

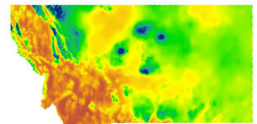

Figure 3(a)

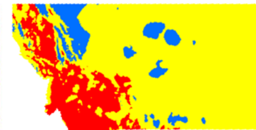

Figure 3(b)

Current Global Temp Average – 100y storm. Rainfall average 4.0043in

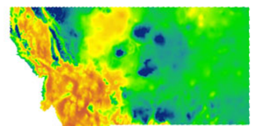

Figure 4(a)

Figure 4(b)

5c Global Temp Increase – 100y storm. Rainfall average 4.6226in

Small changes can have massive impacts. Figure 3a describes rainfall depth of the 100year storm at the current Global temperature, and Figure 4a describes the same, but with a 5-degree temperature increase. While the maps may look the same, the small difference in rainfall results in an extra 1.5 Trillion gallons of water for this given storm event.

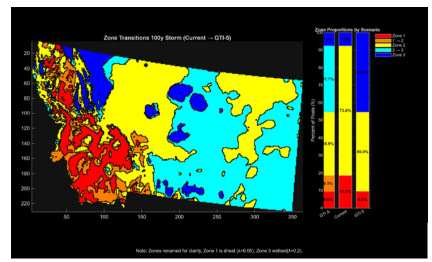

Figure 5 – Zone overlay map for 100y storm with changing Temperature

Figure 5 combine's Figures 3(b) and 4(b) into a geographical analysis of zone change. There is only a negligent amount of raster data from 3(b) transitioning to a drier state in 4(b), indicating increasing temperature averages exclusively increases rainfall.

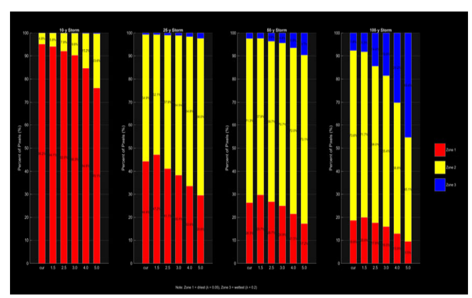

Figure 6 – Zone quantities, grouped by return period

Don't underestimate runoff….

- Weaverville NC, after hurricane Helene

Conclusions

General Trends

As seen in Figure 6, both higher return periods and higher temperatures indicate higher rainfall totals. λ=0.05 produces higher runoff predictions for short return periods and drier climates, and λ=0.2 for longer returns and wetter environments. There is no universally preferred value for the λ variable, one just fits specific storm events and environments better than the other, and we use hydrologic conservatism to decide between the two.

Conclusions

Accurate rainfall is one of the most essential requirements for hydrologic design. We use these rainfall values in tandem with models to estimate the amount of runoff these storms will produce. Given our uncertainty within the models, we use hydrologic conservatism to embed an additional factor of safety in our predictions. But these models were derived before the idea of a non-stationary climate, and with increasing rainfall because of climate change, we have geographically and quantitatively showed shifts in the preferred λ value.

References

Moglen, G. E., et al. "Geographic Dependency of the Curve Number Method's Initial Abstraction Ratio." *Journal of Hydrologic Engineering*, vol. 30, no. 4, 2025, https://doi.org/10.1061/JHYEFF.HEENG-6496.

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