An Examination of Statistical Methodologies in *Alila et al.* [2009] and *Gupta et al.* [2015]

FRST 590: Statistical Methods in Hydrology

Submitted: 29 March 2019 **Prepared by**: Dan Kovacek (35402767)

1.0 Introduction

Runoff at the catchment level is a complex network of mechanisms and their confounding interactions. In the field of hydrological research, there are numerous and varied approaches to the measurement and prediction of runoff, as well as in the attribution of trends in observed data to their potential drivers. (A. Viglione et al. 2016) While there is a current trend favouring process-based analysis over purely empirical approaches, there remains a lack of consensus in the definition and measurement of hydrological connectivity. (Bracken et al. 2013) Variety in methodology may be positive for scientific progress. However, the literature often contains value statements unrelated to scientific debate, invoking language of blame and failure, and putting at risk more than the specific line of research. (Lloyd and Oreskes 2018)

A commentary on the current state of research in the effect of changing land use and land cover (LULC) on streamflow and floods at the catchment scale is presented in *Rogger et al.* [2017]. In the process of delineating gaps in the existing research, the authors describe the need for new approaches to obtain more general statements on impacts, citing the regularity with which studies obtain contradictory results for the same "kind of change", or intervention. *Rogger et al.* [2017] highlight two studies ostensibly to demonstrate typically conflicting results:

> *"Some recent publications such as the paper of Gupta et al. [2015] on the relative impacts of climate and land use changes on streamflow or that by Alila et al. [2009] about the effects of forest practices on floods have triggered scientific debates with the results being criticized by many scientists."*(Rogger et al. 2017)

To gain more quantitative insights into LULC effects on hydrological trends, perhaps new quantitative approaches are needed, as *Rogger et al.* [2017] argue. A better understanding of appropriate use and explanatory power of existing approaches may be equally valuable. To begin, there appears to be epistemological disagreement in the preceding quotation, in the context of their criticism of the discipline:

> *"Studies that examine the impact of land use changes on streamflow and floods often obtain contradictory results for the same kind of change. Although results from individual studies are legitimate, it is*

difficult to obtain general statements on the impacts since each study takes a rather narrow and study-specific perspective."(Rogger et al. 2017)

If studies investigating attribution of the same intervention arrive at contradictory results, one or both must be false. Alternatively, if the methodologies from individual studies are in fact both valid, they must be measuring different interventions, or quantifying disparate outcomes of interventions. Testing for cause and effect is difficult, and discovering causes of effects is even more difficult. (Pearl 2009) The aim of this paper is two-fold:

1. Compare the hypotheses of Gupta et al. [2015] and Alila et al. [2009] from an epistemological perspective.
2. Evaluate the methodologies of Gupta et al. [2015] and Alila et al. [2009].

In terms of the hypotheses (1), while Gupta et al. [2015] focus on the driving factors of a detected increasing trend in *mean annual* runoff, Alila et al. [2009] focus on the effect of forest harvesting on *peak annual* runoff, in terms of frequency and magnitude. The two hypotheses are distinct, but may not be entirely unrelated, as will be discussed. The framework to evaluate methodologies (2) is based on Mertz et al. [2012], who propose as ingredients of attribution: evidence of consistency, evidence of inconsistency, and provision of confidence interval.

2.0 Study Summaries

In the subsequent sections, a condensed synopsis is presented, along with a brief summary of the commentary elicited by each study. Reproduction of results is not the purpose of this paper as the hypotheses of the studies differ sufficiently, making direct comparison difficult. Instead, a discussion of the epistemological nature of the two studies is developed in Section 3 to arrive at a common territory to enable meaningful comparison.

2.1 Synopsis of Gupta et al. [2015]

Analysis of measured runoff in 29 watersheds in Iowa and Minnesota demonstrates an increasing trend of annual runoff, coincident with a positive trend in annual precipitation. Gupta et al. [2015] attempt to quantify the relative influence of precipitation and LULC to the observed increase in runoff. A secondary goal of the study is looking into the confounding effects of changing crop systems and loss of wetlands to explain the observation of approximately constant evapotranspiration (ET) over time.

Gupta et al. [2015] separates the measured record into two periods consistent with a Before-After-Control-Impact (BACI) analysis framework, citing extensive adoption of plastic drain tile in agricultural practices in the mid-1970s as the LULC intervention, as adopted in numerous previous studies (refer to Gupta et al. [2015]). Using annual precipitation and runoff volumes, Gupta et al. [2015] posits that a change in the linear relationship between precipitation and (the natural logarithm of) runoff should be indicative of a change in how the watershed converts precipitation to streamflow. (Foufoula-Georgiou et al. 2016)

Gupta et al. [2015] tests for shifts in streamflow versus precipitation relationships using a series of models of varying complexity, presented in more detail in the subsequent section. The study found the model coefficients to be statistically significant at the 5% level for 19 out of 29 watersheds using a multivariate linear regression model, and additionally all 29 watersheds exhibited a shift in 5-year moving averages of precipitation vs. runoff. Given these observed trends, the authors conclude that precipitation was the sole driver of increased streamflow, and LULC did not make a significant contribution.

In terms of the secondary question of ET, Gupta et al. [2015] conclude that despite substantially different potential ET in the predominant crop systems over the two time periods, no statistically significant trend in ET over time was found.

2.2 Gupta et al. Model Methodology: ANOVA

Runoff and precipitation data from 1966 to 2009 were used in the BACI study, with the breakpoint between the two periods, corresponding to widespread adoption of plastic tile drainage in agriculture, set at 1975. The system of models are described by the following equations (1), (2), and (3):

$$ln(Q_{all}) = \beta_0 + \beta_1 \cdot P_{all} + \beta_2 \cdot I + \beta_3 \cdot P \cdot I$$

(1)

$$ln(Q_{all}) = \beta_4 + \beta_5 \cdot P_{all} + \beta_6 \cdot I$$

(2)

$$ln(Q_{all}) = \beta_7 + \beta_8 \cdot P_{all}$$

(3)

Statistical tests of the coefficients ($\beta_0, ..., \beta_8$) are used to measure whether the relationship between streamflow and precipitation for the two periods of interest are better represented by

In each model, I has a value of 0 or 1 based upon the period, such that pre and post-change periods are assigned to separate coefficients. ANOVA tests for significant difference in the

Temporal trends in annual precipitation are demonstrated in two ways, one using the Mann-Kendall nonparametric test, and the other by calculating mean annual precipitation for three periods: 1920-1949, 1950-1979, and 1980-2009.

-where does the moisture come from?

-what about uncertainty in ET estimation? Methodology:

$$ET = PPT - Q - \Delta S - D$$

Pan evaporation is a measure of evaporative demand, and is driven by humidity gradients, temperature, wind speed, and solar insolation. (Roderick et al. 2007) Investigating a widely observed global trend in decreasing pan evaporation, *Roderick et al.* [2007] modeled the components of evaporative demand and attributed the decline in measured pan evaporation between 1975 and 2004 to a reduction in wind speed along with regional reduction in insolation. Note that pan evaporation data were used based on a single location to represent evapotranspiration across all of Minnesota and Iowa. Average wind speeds are spatially variable across Minnesota and Iowa (Harding and Snyder 2012)

-Gupta says seasonal runoff ratio changes are not appropriate due to dependence of runoff on antecedent soil moisture in previous season.

The study cites evidence of the spread of agrigultural practices, including the use of drainage ditches and subsurface drain tile, beginning in the early 1900s. This assumption thus neglects the existing drainage and subsurface drain tile, in use for three quarters of a century prior to the set breakpoint in study periods (1975). Numerous related studies viewing widespread adoption of plastic drain tile in the mid 1970s as the major cause of increased runoff ((K. E. Schilling and Libra 2003), (Broussard et al. 2008), (Wang and Hejazi 2011), (Xu et al. 2013), (Schottler et al. 2014)). But without evidence of performance and/or soil moisture measures to defend the null hypothesis (no effect of drainage tile), the intervention being investigated is then limited to the performance of modern plastic drain tile versus the older clay tile.

Alila: -dominant process theory (moderate correlation between April 1st SWE and peak flows) -frequency pairing -chronological pairing -what does Alila say are the causes of changes in variability? What are the ways he suggests this is demonstrated in the data? -what is the logical fallacy of composition? The inference that something is true of the whole from the fact that it is true of some part of the whole

-in pursuing the argument of the effect of forest storage on the frequency of floods, there is an implicit argument that forest harvesting, which tents to increase variability of runoff, changes the FFC. If the effect of forest harvesting translates the FFC in the positive vertical direction, the mean is necessarily affected. If the effect of forest harvesting has no effect on the lowest probability events, but has an effect on the higher probability events, the mean is necessarily affected. The logical

Gupta: -chronological pairing -ANOVA/ANCOVA

-possibility of delayed or transient effects of intervention (Murtaugh 2002)

-autocorrelations are not characteristic enough to distinguish random from deterministic chaotic signals (Sivakumalan 2017)

-Interaction between variables occurs in many different ways (often in feedback forms) and in varying degrees of nonlinearity, and so the variables are interdependent on each other, i.e. every variable is dependent on every other variable in a direct or indirect way. The hydrologic cycle is an excellent example of nonlinear interactions and interdependencies among variables, since every component in the hydrologic cycle is connected with every other component, either directly or indirectly (Sivakumar et al. 2017;2016;2011;)

1. What are the interventions being investigated?
2. What are the specific hypotheses?
3. Are the hypotheses consistent with each other, or diametrically opposed?

Summary of *Gupta et al. [2015]*

Objective

Methodology

Supporting Evidence

Commentary

Summary of *Alila et al. [2009]*

Objective

Alila argues pairing of floods in ANCOVA and ANOVA fail to account for changes in flood frequency due to deforestation.

-investigate point about original intent of ANOVA/ANCOVA for detecting changes in means. Is it appropriate to use for extremes? ANOVA/ANCOVA don't account for changes in variance. How to show this?

Methodology

Supporting Evidence

Commentary

> *"Rather than idealized angels of reason, scientific models are powerful clay robots without intent of their own, bumbling along according to the myopic instructions they embody."* (McElreath 2018)

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