Technical note comparing two storm-separation (storm-definition) techniques: Digital Filter (baseflow separation) and Messina’s Stage-Threshold method

Intro

* For event-wise analysis the storm separation technique can be critical   
  defines the start and end of a storm (defines total Q)
* Gellis: The number of peaks in an event and their magnitudes are variables that can influence suspended-sediment characteristics (Walling, 1974).
* can treat multi-peaked events as combined or separate
* can include/exclude small events
* used to classify “storm” vs “non-storm” SSC samples
* Many good studies don’t include info on how storms were separated/defined
  + No description (Loughran et al. 1986; Hicks 1990; Rankl 2004; Nearing et al. 2007; Duvert et al. 2010; Zimmermann et al. 2012) (Tropeano 1991)=no access
* Mention but not in detail?
  + (Basher et al. 1997, 2011) used (Hewlett and Hibbert 1967) baseflow separation and minimum peak flow
  + Events with minimum peak flow (Fahey et al. 2003)
  + Peak flow at some threshold of specific discharge (Q\* = 0.0016 m3/s/ha) with some recurrence interval (Lewis et al. 2001)
* SSYevent equation needs start and end of storm:
* How to define start of storm?
  + Visual identification of start of hydrograph rise (Lewis et al. 2001)
  + Easier to define start than define end
  + Another important issue is how to then define what is the precipitation for that storm (ie some time window prior to hydrograph rise)
* How to define end of storm?
  + Hard to define, unless start of new storm (new hydrograph rise); The ending time was selected by observing the storm hydrograph for all stations and determining either the time of the next storm, the next significant rainfall, or a stable low-flow recession at all hydrographs, usually within about 3 days after the peak. (Lewis et al. 2001)
  + quickflow hydrograph separation point described by (Hewlett and Hibbert 1967)(cited in (Dunne and Leopold 1978) pg 288)
  + Special methodology (Gellis 2013)
* Special issues when dealing with multiple peak storms (complex events (Gellis 2013))?
  + Gellis: In complex events, the recessional portions of the storm hydrographs approach but never reach base flow as defined for regular events
  + Gellis: the individual runoff portions that make up the complex event may be considered isolated because discrete rainfall events are responsible for each rise in runoff
  + Gellis: if you miss a part of a complex event have to throw out the whole thing
  + How to quantify what the “peak Q” in complex storms (Gellis 2013):
    - For multi-peaked events, a peak is defined by a minimum difference in discharge from the immediately preceding trough to the peak
    - Qmax in subsequent event (Qmax\_sub) is the trough minus the peak, and that Qmax\_sub must be a minimum peak flow (different than other peak flow criteria)
  + Separate storms if >24hrs between the peaks; Q decreased by >= 50% (Lewis et al. 2001)
  + Complicates the summation of storm precipitation if subsequent precipitation near end of storm actually makes a new storm event on the hydrograph
* Special issues when using multiple discharge stations?
  + Time of start/end different at different stations (Lewis et al. 2001); they used different start times but the same end time for all stations
  + Some peaks are higher at different stations, so for a multipeak event, which station defines the highest peak? (Lewis et al. 2001)

**Approaches to storm definition**

* Traditional Hydrograph separation (Dunne and Leopold 1978) aka baseflow separation (Graphical methods?)
  + Estimate baseflow, then determine where quickflow starts, stops
  + Traditionally implemented for determining storm runoff (rainfall-runoff modeling)
  + “The techniques of hydrograph separation are all arbitrary and have little or nothing to do with the processes by which stormflow is generated, but if one method is employed consistently, then usable results are obtained.”
  + KEY POINT: **some method must be used to move the analysis forward AND must be “consistent”**
  + However Duvert 2012: It should be noted that due to the number of sites studied here, data processing and validation was not carried out by a single operator. Discharge and sediment data used for this study were initially processed by each of the local operators. Therefore, *some criteria could slightly differ from one site to an- other, such as for instance the way of separating two successive flood events*. This can partly explain the discrepancies observed in the number of events per year.
* **Digital filtering technique used in SSY from Faga’alu paper** (Nathan and McMahon 1990):
  + This base flow separation procedure is based upon a recursive digital filter commonly used in signal analysis and processing (Lyne and Hollick 1979). The filter is of the simple form
  + where fk is the filtered quick response at the kth sampling instant, yk is the original streamflow, and α is the filter (=0.9-0.95; best 0.925); the filtered base flow is thus defined as yk -fk.
  + Digital filter technique. Just as arbitrary as the other methods but is objective and repeatable. Filter parameter alpha=0.9-0.95. Default is 0.925. Three passes, forward, backward, forward again.
  + Nathan 1990: Compared to the smoothed minima technique the digital filter method is better suited to low base flow conditions, is less variable, and is more strongly correlated with other low-flow indicators. And more similar to results from manual approach.
* **Rule-based/Criteria scheme** (Gellis 2013)
  + Minimum peakflow (hourly discharge) > 95th percentile (published in table)
  + End of storm:

Graphical inflection point in the recession limb, where stormflow ceases

* + - Defined by second derivative of a 3rd-order best-fit regression line to the recession portion of the hydrograph
    - The second derivative of a 3rd-order equation is the inflection point of the curve or where concavity changes (Hughes-Hallett, 1994)
    - Also: for the inflection point to be considered the end of the event, the recessional limb of the storm hydrograph had to fall below a threshold base flow and reach a threshold slope. The threshold base flow and slope of the recessional limb of the storm hydrograph were based on analysis of base-flow recession curves.
  + Complex event hydrographs were delineated into separate runoff events based on the following criteria:
    - A threshold discharge and a threshold slope were developed for the recessional portion of the hydrograph for each basin
    - The threshold discharge was based on examination of recession curves and was always higher than the value used to determine the end of a single event
    - If the hydrograph recession met the threshold discharge and threshold slope criteria, the end of that portion of the complex event was selected just before the next hydrograph rise.
    - Last part of complex event goes by normal end of storm criteria
* **Stage-threshold approach (my first approach)**
  + Storm event starts when stage exceeds the “storm threshold” (=mean long term stage + 1 standard deviation)
  + Minimum time = 2 hours
  + If the end of one event is the same time as the start of another event they are combined
  + “Storm precipitation” is up to 1 hr before the stage rises over threshold
  + Very simple compared to other methods, especially (Gellis 2013)

for this research the simple stage height threshold rule was used due to the flashy hydrologic response, low baseflow discharge, and short duration of recession curves between events (Fahey et al., 2003; Lewis et al., 2001). A storm event was defined as the period of time when stream stage height exceeded a given threshold for a minimum of two hours. The storm threshold was defined as the mean stage recorded over the study period, plus one standard deviation and the term "baseflow" is used to designate periods when flow was below the storm threshold or exceeded the threshold for less than two hours. Complex storm events occurred when additional rain fell before the stream stage fell below the storm threshold. Events with multiple Q peaks were separated into separate events if the peaks were separated by at least a two hour period and Q was near the storm threshold. Several small events produced sediment runoff and high SSC but did not meet the storm definition criteria to be included as a storm event.

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| Method | Start | End | Complex Event Separation Technique | Minimum Qmax Criteria | Advantages | Disadvantages |
| (Hewlett and Hibbert 1967)  Cited in  (Dunne and Leopold 1978) | Visual; rise in the hydrograph | Calculate baseflow slope; where the line meets the hydrograph recession limb | None provided | No | Relatively simple |  |
| (Lewis et al. 2001) |  |  |  |  |  |  |
| (Gellis 2013) |  |  |  |  | Though criteria may be arbitrary or “qualitative” they provide standardization | Complex data analysis; criteria definitions may be incorrect |
| Digital filter | Where Quickflow goes above 0 | Where Quickflow drops to 0 |  |  |  |  |
| Stage threshold | Where stage surpasses threshold (=mean stage + 1 std) | Where stage falls below threshold (=mean stage + 1 std) |  |  | Simple  Automatic: good for lots of storms | Works where baseflow is consistent and hydrograph is flashy |
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