Impacts of Watershed Delineation on Modeled Runoff from Summer Storms

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Rationale

• Modeled Runoff after storms is used to:
  • Determine regulatory limits
  • Plan for storm events

• Watershed Delineation Determines Modeled Area*

• Are watersheds containing Internal Drainage being delineated correctly?

*Jensen 1988
Filled-Sink Delineation Problem Areas

- Karstlands
- Glaciated areas
- Excessively arid areas with less than 20 cm precipitation
- Sandy areas, more than 50 percent covered by sand
Study Objectives

• How do different delineation methods perform?

• Watersheds in North WI & MN
  • Uneven Topography
  • Internal Drainage
    • Wetlands & Bogs
  • Low Agriculture & Development
Filling Sinks in the Digital Elevation Model

Unfilled → Filled
Filled Sink Delineation

Works well with:
- High drainage density
- High relief

Problematic:
- Low drainage density
- Low relief
- Internal Drainage
Internally Drained Areas in Watersheds

- Isolated from drainage networks
- Can lead to Error in GIS runoff models*
- Common in upper Midwest **
- May contain bogs, lakes, internal drainage networks

*Taylor 2012  **Richards 2004
Previous Studies

Richards 2004: Potential Contributing Source Areas

- Huron River Watershed, Michigan
  - Internal Drainage
    - 37% smaller than filled sink delineation
  - Unfilled DEM
    - Delineates outward from drainage network
Previous Studies

Macholl 2011 – PCSA in Wisconsin

• Four small watersheds in northwest WI

• PCSA performed better than filling sinks

• Few storms occurred during study
Methods

• 3 Watershed Delineation Methods:
  • Filling Sinks
  • Cutting Sinks
  • Potential Contributing Source Areas (PCSA)

• Modeling Runoff: NRCS Curve Number

• Observed Runoff - USGS
- 7 Watersheds
- 10 mi² - 300 mi²
- Internal Drainage

% Internal Drainage

Bear River
Allequash Creek
Knife River
White River
Whittlesey Creek
Fish Creek

Sources: WI DNR, MN DNR, USGS
Created by: Bill Troolin
Data Inputs & Sources

**Spatial Data**
- **Elevation** – 10m DEM
  - NED-10m (USGS), LIDAR 1m (MN-DNR)
- **Land cover** – NLCD
  - (USGS)
- **Hydric Soils**
  - (NRCS)
- **Streams and Lakes**
  - (WI-DNR, MN-DNR)
- **Roads and Borders**
  - (WI-DNR, MN-DNR)

**Tabular Data**
- **Precipitation**
  - (NCDC, NWS)
- **Discharge**
  - (USGS)
Delineation Method 1: Filled Sinks

- Fast & Easy
- Boundaries may include Internal Drainage

**Problem factors:**
- Low Drainage Density
- Internal Drainage
- Low Relief
Delineation Method 2: Cut Sinks

• Where were Sinks filled?
  • Identify sinks
  • Remove sinks
    • Filled cells reclassified as NoData

• Model runoff using modified watershed area
Identifying Internally Drained Areas

- ArcMap Raster Calculator
- Reclassify cells with elevation change as No Data

Filled DEM

Unfilled DEM

Cut Watershed

Connected

Internal Drainage
Method 3: Potential Contributing Source Areas

- **Initial Input:**
  - Streams and Lakes
  - Floodplains, Wetlands

- Delineates outward from Initial Input

- Increased accuracy

- More data & time intensive
PCSA Delineation

- Stream
- Initial Contributing Area
- PCSA Delineation
- Non-Connected
Internal Drainage
Surface Water & Floodplains

Allequash Watershed Elevation

Allequash Creek Initial Contributing Area

Watershed Features
- Surface Water
- Floodplains
- Filled Watershed

Legend:
- Lakes
- Streams
- Elevation

High
Low

Miles: 0 0.5 1 2

Miles: 0 0.5 1 2
Modeling Storm Runoff

- NRCS Curve Number Equation

\[
Q = \begin{cases} 
0 & \text{for } P \leq I_a \\
\frac{(P-I_a)^2}{P-I_a+S} & \text{for } P > I_a 
\end{cases}
\]

\[
S = \frac{1000}{CN} - 10
\]

\[
I_a = 0.2S
\]

- Hydric Soils
- Land Use

- Results compared to Discharge

Flow Components - Bear River

Discharge (cfs)

- Total Flow
- Baseflow
Selecting Storms

• Summer Precipitation
  • Summers within 1 Standard Deviation of watershed average

• Isolated storm events

• Largest responses in the gage records
  • Discharge & Precipitation
Precipitation Gauges : The Plan

• The Plan:
  • Thyssen Polygons based on multiple gauges

• Most accurate representation of where rain fell
Precipitation Gauges: The Reality

- Normally only one gauge

- Best solution:
  - One rain zone for whole watershed
  - Limit watershed size
Analysis of Results

- **Model Error:**
  \[(\text{Model Runoff}) - (\text{Observed Runoff})\]

- **Normalized Error:**
  \[
  \frac{\text{(Model Error)}}{\text{(Watershed Area)}} \text{ (ft}^3\text{)/(ft}^2\text{)}
  \]

  - Useful with watersheds of varied sizes

Error compared to:
- Drainage Density
- Watershed Area
- % Internal Drainage
- Landcover types
Results: Differing Behavior by Storm Size

• **Small Storms:** (Under 0.2 feet)
  • Indications of possible trends

• **Large Storms:** (Over 0.2 feet)
  • Fewer indications trends than small storms
Filled Delineation vs Drainage Density
Small Storms

Normalized Error

Drainage Density

Error Bars = 1 Standard Deviation
Normalized Error vs Drainage Density
7 Watersheds – Small Storms

Normalized Error vs Drainage Density

Fill
Cut
PCSA

Error Bars = 1 Standard Deviation
Normalized Error vs Drainage Density
7 Watersheds - Large Storms

Error Bars = 1 Standard Deviation
Normalized Error vs % Internal Drainage
Small Storms

 normalized Error

 % Internal Drainage

 Error Bars = 1 Standard Deviation
Normalized Error vs % Agriculture
Small Storms

Normalized Error

% Agriculture

Error Bars = 1 Standard Deviation
Conclusions

Based on Current Watersheds:

**For Large Storms**
- All models perform similarly
- Accounting for individual Watershed & Storm Characteristics is key

**For Small Storms**
- PCSA tends to underestimate
  - More suited for surface water pollutants than direct runoff volumes?
- Additional calibration required for PCSA?
  - Culverts, Overflowing wetland sinks
Additional Questions

• Why does model performance vary with storm size?
  • Are there other important variables?
    • Relief
    • Watershed Shape
  • Is antecedent moisture being accounted for?

• 3-5 additional watersheds being modeled
  • 10-12 watersheds total


