Hydrology and Reality
Are your results in the realm of reality or even possibility?
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The purpose of this presentation is to highlight methods to determine if the results of dynamic hydrologic models are reasonable. Potential solutions to some of the challenges hydrologic modelers encounter are also presented.

Unlike in other fields of engineering, hydrologic calculations should be treated as a guide and often must be over-ruled with logic.
What are the Problems?

1. Models are almost useless without calibration!
   - Hydrology is not an exact science
   - Hydrologic modeling simplifies millions of natural variables

2. It can be challenging to recognize an error without real world data for comparison.

3. Design manuals and standards ensure consistency, not accuracy.

4. Misuse of equations
   - Equations derived from limited range of data, i.e. slope 1 to 5%
What are the Problems?

“Doing something wrong for twenty years does not make the method right but the consistency of the results can give you tremendous confidence in your answer.”

-Ted Cassidy

Consistency does not mean accuracy!
How Accurate are Uncalibrated Rainfall Runoff Models?

• Hoesein et al, 1989
  • The SCS method “has been tested extensively in the deterministic sense with generally poor results…”

• Wood and Blackburn (1984)
  • Used 1,600 runoff plots in NV, TX and NM
  • Compared the difference between observed and computed flood peaks > 50% in 67% of the time

• USACE EM 110-2-1417 warns:
  • “…These methods (Green-Ampt and Holtan) assume an overland flow-type mechanism which is not entirely appropriate for forested areas where a subsurface mechanism tends to control direct runoff.”
Why a Rainfall Runoff Model?

• The scope just says we will create one!

• May need because floodplain volume is more critical than floodplain conveyance

• May need to perform time dependent simulations
  • i.e. Reservoir simulations, flood forecasting, hydro-period assessment etc.
Finding Calibration data

• There is **always** calibration and validation data! We just need to research it:
  • Knocking Doors
  • High Water “Marks” (HWM)
  • Newspapers and Media
  • Internet – NOAA, USGS, Youtube
  • Field Data Collection
  • Flood Insurance Claims
  • Textbooks
  • Regression Equations
Knocking Doors - Put the questions in layman terms…

• Did that road overtop?
  • No is the most useful answer.
  • Yes may be because of debris.

• Were you able to get home? (flow over road)
• Did water get into your house? Garage? Yard?
Knocking Doors - Put the questions in layman terms…

• When did it happen?
  • Was it dark when the water got the highest?
  • Was it raining when you left for church? When you got home?

• How bad was it?
  • Was it over your knees?
  • Had you ever seen it this deep before?
  • Did your parents talk about the ‘64 flood? Did your house flood then?
Knocking Doors - Validate Consistency

• Are witness accounts consistent?
  • Triple validate – Obtain the same information from at least 3 different sources or angles.

• Do sources have a hidden agenda?
  • Are they trying to get political attention for help and community actions?
  • Are they looking to get acquired and want to exaggerate damage?
HWM’s - Calibration vs Validation

Validation - Knowing a culvert that didn’t overtop defines an upper limit to the flow.

A HWM does not have to be surveyed to be useful!!
US Bureau of Reclamation charts are a quick way to estimate culvert capacities.
Calibration - Knowing a peak elevation defines the maximum observed elevation.

A HWM survey can be very useful!!
Media: What do these pictures tell us?
Media: What do these pictures tell us? What is considered safe?

- Velocity × Depth > 7.3 to 23 will likely sweep you away.
- Stability depended on the weight and height of participant – Check out the guys smile, what does it tell us?
- The recommended maximum safe Velocity × Depth product is 10 ft²/sec.

Media: What do these pictures tell us?

• D = approx. 3.5 ft
• If the V*D >10 I don’t think he could carry this TV with smile on his face!
• Therefore velocity is likely < 3 feet per sec
• Also, water is not piling up against their bodies
  • Velocity must be low
Media: What do these pictures tell us?

- In this picture (R), there is no pile-up of water against the car. The wave in front is caused by the car’s movement.
  - Velocity of flow must be low
What do these pictures tell us? Basic Fluid Dynamics in Action

What can we learn from Velocity Head (h)?

- If flow is obstructed, the velocity $V = 0$, then $h = 0$
- If $V = 0$ then Water Surface = Energy Grade
Media: What do these pictures tell us?

- **Estimate Velocity Head**
  - \[ \frac{V^2}{2g} = h \]
  - To the right \( h \) is about 2, so \( V \) is > ~10 ft/sec!

- The velocity at the car is much lower or the car would be swept away.

- “As little as a foot of water can sweep your car away.”
  
  NC Dept. of Public Safety
## Velocity Head and Velocity

<table>
<thead>
<tr>
<th>Velocity Head (h) (feet)</th>
<th>Velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
</tr>
</tbody>
</table>

\[ h = \frac{v^2}{2g} \]
Media: What do these pictures tell us?

- Water may have been deeper, but it was at least to the bottom of the street sign.
- Can use LiDAR point plus measured height.
  - Potentially derive from point cloud
- Contact neighbors the picture and ask if was higher.
The Realm of Possibility
What is the problem?

- Hydrologic results can be easy to determine, however results can often be impossible!
  - Hydrologic methods can often be incorrectly applied
  - Hydrologic methods often have limitations
Rational Formula $Q = CIA$

Rule 1: Water can’t run off faster than it is falling from the sky.

$C = 1$ (100%) (unless it is diverted from another area)

$I =$ Intensity in inches per hour - Get curve from local jurisdiction website.
Rational Formula as a Validation Tool

ACTUAL PROBLEM: 20 acre site Q100 = 157 cfs.
Is this reasonable?

- Can the 100-yr flow be 5,024 cfs/sq mi for a 20 acre site?
- Estimate Tc for 20 acres > 20 minutes.
- 100-yr 30 minute rainfall = 5.8 inches per hour.
- Q falling from the sky = 1.0 x 5.8 x 20 acres = 116 cfs
- 116 x (640/20) = 3,712 cfs per square mile.
Rational Formula as a Validation Tool

• Considering C is 0.4 for residential areas the maximum flow rate from a 20 acre residential area is about 1,485 cfs/sq. mile.

• For undeveloped land, C = 0.1 to 0.2, so Q runoff would be around 495 cfs/sq. mile.
The source of the problem was the definition of SLOPE. In the regression equation, SLOPE was defined as the slope of the RIVER as shown on the 1:100,000 scale quad map.
Plotting Regional Max. Observed Flow

If we see a model results in the West with Q for 5 sq. miles > 600 cfs / sq mi, it is likely to be wrong.
The USGS report will say the equation is applicable from the smallest to largest points in the data set. Review the data. How well does the smallest watersheds fit? How many points did they have at the lower limit?
Verify with Bulletin 17B Log Pearson Analysis of Nearby Gages

- It only takes a few minutes to run a PEAKFQ! Run it on all gages in the area with more than 25 years of data.

- Understand the sensitivity of a short range of data
Verify with Bulletin 17B Log Pearson Analysis of Nearby Gages

<table>
<thead>
<tr>
<th>Analysis Range</th>
<th>Years of Record</th>
<th>100-yr Flow Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full records</td>
<td>60</td>
<td>20,300</td>
</tr>
<tr>
<td>1950 - 1964</td>
<td>15</td>
<td>23,300</td>
</tr>
<tr>
<td>1957-1971</td>
<td>15</td>
<td>37,650</td>
</tr>
<tr>
<td>1962-1976</td>
<td>15</td>
<td>8,329</td>
</tr>
</tbody>
</table>

• If we had only 15 years of record, the estimate would potentially be less than half of the 60 year estimate!
Why are Uncalibrated Models so Inaccurate?

• Approximately 75% of the error in a rainfall runoff model is due to inaccurate estimation of Time of Concentration or Travel Lag.

• The Tc is often under-estimated, especially in steeper terrain resulting in greater peak estimates.

• Most equations were developed on slopes less than 5% and should not be extrapolated to steeper slopes.

• The time lag is also underestimated because we assume a constant normal depth and velocity in the Tc calculations.
Understanding Hydrologic Routing, Flood Celerity and Velocity
Manning’s Values are not Constant!

- Values are highly dependent on stage and discharge
- Other influencers:
  - Seasonal variation
  - Erosion and sedimentation
  - Debris
- How does this influence hydrologic routing?

Source: USACE HEC TD-13, 1982 - Mississippi River at Arkansas City (Figure 4, Page 10)
Hydrologic Routing and N Values

- Hydrologic routing concerns the entire hydrograph
  - Channel routing is highly sensitive on N values

Example: 6 mile long HEC-HMS channel routing…

When N increases from 0.04 → 0.08:

- $Q_{\text{max}}$ decreases 35%
- Reach lag doubles
Hydrologic Routing and N Values

- Hydrologic channel routing N values and hydraulic cross section N values do not have to match
  - Consider using vertical variations in N values where available (ie for HEC-RAS cross sections)
  - For hydrologic routing, use a hydrograph averaged N value if vertical variations are not supported (ie HEC-HMS 8-point routing cross sections)
    - Hydrologic routing N values should be higher than hydraulic model cross sections
  - If using constant vertical N values in a hydraulic model, determine which stage is most critical to calibrate to (ie 1% flood for FEMA studies)
Timing and routing! Plot hydrographs along a river for various storms.
Measure Tc in the Field (especially for Expert Witness)

Tc is theoretically constant (not really, but with Tc for a bank full flow will be close to a flood Tc). If there is a gage on the stream you can review rainfall and flow data to determine the consistency of Tc.
What Velocities Are Reasonable?

• Even in mountain streams, flows over 10 feet per second are very rare.

• The maximum velocity I can find ever recorded at a single point of a naturally flooded cross-section is 22.5 feet per second. The average velocity in the section was about 11 ft/sec. – Ted Cassidy

• Gaging flows over 10 ft/s is extremely challenging
St Francis Dam Case Study

• St Francis Dam Failure

• A peak flow of 1.7 million CFS was estimated just downstream of the dam

• When the dam failed, a 140 foot wall of water rushed out at approximately 30 feet per second. By time it reached the ocean it was moving at 5 mph (7.3 ft/sec). The wave traveled 54 miles in 5.5 hours. (Note: Celerity = 1.67 * velocity)
Steep Reach Stream Velocities

• Which gets you to the bottom first?
  • Going down the slide? or
  • Falling and bouncing down the steps?

• Is a natural channel more like a slide or steps?

• For hydrologic modeling, should we simply take the change in elevation and reach length to determine slope?
Steep Reach Stream Velocities

- What is the horizontal velocity of a vertical drop? ZERO!
- When water falls vertically, it loses its horizontal momentum and velocity.
- The distance you measure on a map is the horizontal distance. Vertical velocity is irrelevant to Tc!
Hydrologic Routing for Steep Reaches

• How do we account for step-tread channel reaches when performing hydrologic channel routing?
  • Raise N values to account for the turbulent flow.
  • Use Jarrett’s equation (1985): \( N = 0.39 S^{0.38} R^{-0.16} \)
  • Calculate an effective grade change and energy slope for hydrologic routing (see below)
Homework Assignments – Channel Velocity

1. Find a river in high flow (with safe access!).
2. Measure a distance.
3. Throw five oranges or sticks in at various locations. Measure the time it takes for the stick to float that distance and calculate average float velocity.
4. Multiply float velocity times 0.88, this typically gives the average flow velocity within about 10%.
5. Repeat this in your driveway and in the gutter.
6. How do the results compare to a model?
Conclusion

• Hydrology is not an exact science
• Doing things consistently and applying standards gives a false sense of accuracy
• Computational models can yield unrealistic or even implausible results
• Leveraging even basic calibration data and understanding the realm of possibility will result in far greater accuracy and defensibility