Hydrology in small catchments

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Presentation Topics

- Principles of Hydrology –
  - rational formula, unit hydrograph
- Modeling Methods
  - SWMMHYMO Synthetic Unit Hydrograph
- Data Collection
  - accuracy, quality control, areas of required improvement
- Data gaps – interpolation and statistical analysis
- Question and Answer
Importance of Hydrology

- Hurricane Tomas in October 2010 and torrential rainfall event in April 2011 and December 2013 caused severe flooding and damage to property and infrastructure.
a – quick surface runoff from excess precipitation
b – subsurface runoff
c – aquifer
d – infiltration
Principles of Hydrology

- **Rational Method**
  - Empirical method for estimating peak flows
    - Assumes a certain fraction of rainfall becomes runoff
    - Accurate for small areas (<80 ha)

- **Unit Hydrograph Method**
  - Watershed based
  - Hydrological modeling
Rational Formula

\[ Q = 2.78CIA \]

- \( Q \) = Runoff (L/s)
- \( C \) = Runoff coefficient (dimensionless)
- \( I \) = Rainfall intensity (mm/hour)
- \( A \) = Drainage area (hectares)
Principles of Hydrology

Rational Method Parameters

- Runoff Coefficients
  - Determine weighted C value for mixed use areas

\[ C_w = \frac{\sum_{j=1}^{n} C_j A_j}{\sum_{j=1}^{n} A_j} \]

- \( C_w \) = weighted runoff coefficient
- \( C_j \) = runoff coefficient for area \( j \)
- \( A_j \) = area for land cover \( j \)
- \( n \) = number of distinct land uses
Rational Method Parameters

- **Runoff Coefficients**

<table>
<thead>
<tr>
<th>Type of surface</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete or sheet asphalt pavement</td>
<td>0.8-0.9</td>
</tr>
<tr>
<td>Asphalt macadam pavement</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>Gravel roadways or shoulders</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td>Bare earth</td>
<td>0.2-0.9</td>
</tr>
<tr>
<td>Steep grassed areas (2:1)</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>Turf meadows</td>
<td>0.1-0.4</td>
</tr>
<tr>
<td>Forested areas</td>
<td>0.1-0.3</td>
</tr>
<tr>
<td>Cultivated fields</td>
<td>0.2-0.4</td>
</tr>
</tbody>
</table>

*For flat slopes or permeable soil, use the lower values
For steep slopes or impermeable soil, use the higher values*
Principles of Hydrology

Rational Method Parameters

• Rainfall intensity
  • Obtain from IDF curves – based on:
    • Time of concentration
    • Return period desired
- IDF curve
Principles of Hydrology

- Time of concentration

![Graph showing time of concentration with annotations]

- Storm duration set equal to Tc - higher peak, small total volume
- Longer storm duration - lower peak flow, larger total volume
Unit Hydrograph

Removing Baseflow from the Hydrograph

Quick-response runoff

Baseflow

Time

Flow

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Important Terms in Unit Hydrograph Theory

- Duration of excess precip.
- Rising limb
- Quick-response runoff
- Recession curve
- Inflection point
- Baseflow
- Baseflow separation line
Removing Baseflow from the Hydrograph

Flow

Time

Quick response runoff only
Calculating the Volume of Quick-Response Runoff

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Computation of Basin-Averaged Excess Precipitation

Total volume of excess \[ \div \] Basin area = Equivalent uniform runoff depth for the whole basin

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\[
\frac{\text{Volume}}{\text{Area}} = \text{Average Depth}
\]

\[
\frac{2,000,000 \text{ m}^3}{100,000,000 \text{ m}^2} = 0.02 \text{ m} = 2 \text{ cm}
\]

\[
\frac{\text{Hydrograph Unit}}{\text{Excess Precip.}} = \text{Adjustment factor}
\]

\[
\frac{1 \text{ cm}}{2 \text{ cm}} = 0.5
\]
Adjusting Unit Hydrograph for Precipitation Magnitude

2.0 units of excess precip.
Original
0.5 units of excess precip.

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Modeling Methods

- SWMMHYMO MODEL
- Unit Hydrograph Method
- Synthetic Unit Hydrograph
- Convolution of Multiple Unit Hydrographs
SWMHYMO Model

Synthetic Unit Hydrograph
(Soil Conservation Service Method)

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Adjusting Unit Hydrograph for Precipitation Duration

Excess occurs in 1 hr
6 hr unit hydrograph
Excess occurs in 12 hr
Bar Graph of Hourly Excess Precipitation Over 24 Hours

Applying Convolution for a 24 hr Event Using a 6 hr Unit Hydrograph for Four 6 hr Periods
Bar Graph of Hourly Excess Precipitation Over 24 Hours

Applying Convolution for a 24 hr Event Using a 6 hr Unit Hydrograph for Four 6 hr Periods
SWMMHYMO MODEL

• Input Parameters:
  o Land use – urban area, agricultural, rainforest, etc (mapping, aerial photography, site visits)
  o Soils – sand, clay, etc (soil maps)
  o Topography – steepness of terrain (mapping, survey data)
  o Rainfall data – includes historical data

• Output: Model generates flow in the river for different rainfall conditions
Input Parameters

- Example Case Mesopotamia Watershed
- Drainage area (ha) and time to peak (63 % of Tc)
- CN (Soil Curve Number)
  - Soil type and hydrological soil groups (A,B,C,D)
  - Topography
  - Landuse
- IMP Imperviousness ratio (% of hard surfaces)
Precipitation

- Precipitation is a natural phenomenon which cannot be controlled
- What we can do is employ tools to investigate the impact of rainfall on property and infrastructure
Return Periods

- The average length of time in years for an event (e.g. flood or river level) of given magnitude to be equalled or exceeded.

- i.e. a 50 year return period is just another way of saying that the storm event should occur on average only once every 50 years
Return Periods

- 106 year stream flow record

Peak flow > 200,000 cfs occurs 3 times

Therefore, 200,000 cfs has a return period of:
T = 106/3
T = 35 years

Peak flow > 100,000 cfs occurs 7 times

Therefore, 100,000 cfs has a return period of:
T = 106/7
T = 15 years
Probability of occurrence

- The probability that an event (of a specified magnitude) will be equalled or exceeded in one year

- Inversely proportional to Return Period

\[ P = \frac{1}{T} \]

If an event has a return period of 50 years then the Probability that it will occur in any given year is

\[ P = \frac{1}{50} \]
\[ P = 0.02 \text{ (2\%)} \]
## Return period and probability of occurrence

<table>
<thead>
<tr>
<th>Return Period (years)</th>
<th>Probability of occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
</tr>
</tbody>
</table>

Severe events occur with less frequency than moderate events.
Return Periods

- Probability of an event occurring:
  - does not change over time
  - is independent of past events

- A 100 year flood can happen multiple times over a 100 year period
- It can happen the following year after a 100 year storm event occurred
- A 100 year flood may not occur event once during a 100 year period
Frequency Analysis

- Frequency analysis relates the magnitude of a storm or flood event to their frequency of occurrence using probability distributions.

- Can be done using rainfall or stream flow data.

- Requires measurements of hydrologic data over significant periods of time.
Frequency Analysis

- Can be completed using computer software
- Involves fitting a probability curve to measurements
  - Can be done for varying lengths of time
    - Annual maximum peak flows
    - Monthly maximum peak flows

Information on how to compete a frequency analysis can be found in: Applied Hydrology, 1988, Maidment, Chow and Mays
Frequency Analysis

Mackenzie River at Fort Simpson
Flood Frequency, 1939-99

Discharge (m³/s)

Return Period (year)

- Observed
- Pearson
- 90% Confidence Limits

Observed values plotted against return period, showing a trend line and confidence limits.
Frequency Analysis

- Can be done where at least 10 years of data are available
- Can augment data with extreme historical events
- Extrapolation
  - should not extend beyond 2 x record length
IDF Curves

Mackenzie River at Fort Simpson
Flood Frequency, 1939-99

FL-DOT Zone 6 Intensity vs. Duration

Rainfall Intensity (in/hr)

Rainfall Duration (minutes)

- 2-Year
- 3-Year
- 5-Year
- 10-Year
- 25-Year
- 50-Year
Precipitation Gauges

- Long term stations:
  - Dumbarton (1970-2013, 43 yrs)
  - Joshua Airport (1987-2013, 26 yrs)

- Tipping bucket:
  - 10 stations
  - Installed in 2008/2009 (5 years)
Availability of precipitation data

- Data is difficult to locate and has not been quality controlled
  - E.g. Dumbarton station data is available in hard copy format only
  - E T Joshua
    - Some of the data is 6 hourly
    - Some of the data is available monthly
  - Tipping bucket stations are provided as raw data
Analysis of precipitation data

- Distribution of precipitation stations is good
  - density of the rain gauge network meets recommended densities by the World Meteorological Organisation for a small island
  - Precipitation stations range in altitude from 44 to 844m

- Significant data is missing from the tipping bucket gauges
Importance of Gauge distribution

- Precipitation amounts vary spatially over the island
  - Orographic effect results in significantly more rainfall in the interior of the Island compared with the coast
  - Historical storm events such as April 2011 and December 2013 were localised events with little impact on the Mesopotamia catchment
Stream flow Gauges

- >7 stations on the windward side
- Data is available as water levels

- Spot measurements are available but only during low flows
  - Not possible to create a rating curve using this information
  - Cross-section information to convert water levels to flow are not available
Recommendations

- Create a hydrological database:
  - Summarize station information (location, elevation, type, data availability etc)
  - Installation of monitoring stations if required
  - Consolidate all available hydrometric data into one location
    - Distribute this information to appropriate personnel
  - Quality control all data
Planning

- Modeling can also be used to examine changes in land use and their impacts on runoff:
  - Deforestation
  - Urbanization
  - Irrigation requirements

- Models of current conditions can be used as a baseline and scenarios examined in relation to current conditions
  - E.g. deforestation results in a 10% increase in stream flow compared to existing conditions
Natural Disasters

- Climate change is expected to cause an increase in extreme events such as flooding
- Impacts of climate change can be examined using modeling in conjunction with climate change models
  - i.e. can look at the impact of a 7% increase in rainfall in regards to the amount of runoff produced
  - i.e. can examine the impact of sea level rises
- Knowing these changes we can begin to plan and prepare for these changes
References

- Some images obtained from UCARs Comet Program
Questions