Impact of Increased Stormwater Runoff on Urban Drainage Systems

William E. Spearman, III, PE

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Contact Information:

William E. Spearman, III, PE
Member, APWA National Water Resources Management Committee
Vice President
Woolpert, Inc.
803.731.0261
bill.spearman@woolpert.com
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Credit Information

This presentation includes research conducted by:

Brian P. Bledsoe, Ph.D., P.E.
Department of Civil and Environmental Engineering
Colorado State University
Campus Delivery 1320
Fort Collins, CO 80523-1320
Phone: 970.491.8410
Fax: 970.491.8671
http://www.engr.colostate.edu/~bbledsoe

Learning Objectives

- Describe the impacts on urban drainage systems when development occurs in a watershed.
- Discern the difference between peak rate runoff controls and volume controls.
- Examine techniques for minimizing these impacts and improving water quality.
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Examine The Subject From Three Perspectives

- Changes in urban stream hydrology
- Changes in urban channel morphology
- Changes in urban stream quality

However, in the end, all three elements are inter-related!
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Urban Stream Hydrology

Changes in Urban Stream Hydrology

- Increased magnitude and frequency of severe floods
- Higher velocities in stream flows
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Changes in Urban Stream Hydrology

- Increased localized flooding

Changes in Urban Stream Hydrology

- Impacts to structures in or adjacent to regulated floodplains
Changes in Urban Stream Hydrology

- Increased frequency of erosive, bankfull floods

Changes in Urban Stream Hydrology

- More annual runoff volume as storm flow
- Less annual runoff volume as baseflow
We have Regulations, don’t We?

- Detention pond requirements
- Release rate rules
- Downstream analysis requirements

Detention Pond Requirements

- Detention/retention basins are typically provided for all new developments.
Overview of Detention Ponds

- Purpose - store and release runoff below target outflow rate(s).
- Design quantities - pond volume, outflow structure type and dimensions.
- Computations - runoff hydrograph, pond routing
- Performance check - peak outflow rate(s).
- Rule of thumb - size pond to store extra runoff volume and you will meet the target outflow rate.

Release Rate Rules

- Single objective rule: Control peak outflow at or below target rate computed as the predevelopment peak rate for a specified return period (frequency) event.

- Multi-objective rule: Control peak outflow at or below target rate for multiple return period events. Implicit objective is to maintain pre-development flood frequency curve control problems with downstream channel degradation.
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Drainage System Analysis

- Impact of new development is analyzed to evaluate:
  - Damage to upstream and downstream properties;
  - Hydraulic overloading of existing drainage facilities; and to
  - Establish the “No-harm” release rate rule to control outflow to not create any problems upstream or downstream.

Why does this Happen?

![Graph showing flow rates over time]
Typical Regulations…

- Follow either the single or multi-objective release rate rules.
- Support the idea that if the outflow rate is not changed, then there is no impact.
- Based on the assumption that the two-year rainfall event produces a two-year storm that is equivalent to a “bankfull” flow.
- Ignore small storms.

Average Annual Precipitation Events
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Urban Channel Morphology

Changes in Urban Channel Morphology

- Channel widening and downcutting
Changes in Urban Channel Morphology

- Increased streambank erosion

Changes in Urban Channel Morphology

- Changes in sediment grain size, different scour/deposition patterns
Changes in Urban Channel Morphology

- Channel modification or relocation

Which Leads to …
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Why does this Happen?

Channel Enlargement vs. % Imperviousness

$ER = 0.970 (A)^{0.870}$

$R^2 = 0.90$
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Storm Flows and Sediment Yields During Project Life

SMOOTHED HYPOTHETICAL TRENDS

Storm Flows and Sediment Yields during Project Life

Q_s + d_s+ \sim Q^+S
Construction Phase - Sediment Delivery ↑
Post-Construction - Sediment Delivery ↓
Q_s - d_s \sim Q^-S--
Incision and / or Widening

2007 Stormwater Summit
September 12, 2007 16
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Construction vs. Post-Construction Flows

Geomorphic Effectiveness

- Threshold of erosion is exceeded
  - Magnitude
  - Duration
- Persistence
  - Frequency vs. recovery rate (depends on climate, vegetation, geology, etc.)
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Responses Vary With Stream Type

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sand bed</th>
<th>Gravel bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed material transport</td>
<td>Continuous</td>
<td>Episodic</td>
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<tr>
<td>Variation in sediment transport</td>
<td>(Velocity)³</td>
<td>(Velocity)³</td>
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<tr>
<td>Armoring</td>
<td>Ineffective</td>
<td>Significant</td>
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<tr>
<td>Bed forms and changes in bed roughness /</td>
<td>Rapidly</td>
<td>Not rapidly adjustable</td>
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<td>configuration</td>
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<td>/ formed by relatively</td>
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<td></td>
<td>flow events</td>
<td>infrequent events</td>
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<tr>
<td>Scour depth</td>
<td>Deep</td>
<td>Shallow</td>
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<tr>
<td>Variation in scour depth</td>
<td>Rapid</td>
<td>Slow</td>
</tr>
<tr>
<td>Slope and Stream Power</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Channel response to changed hydrology</td>
<td>Rapid</td>
<td>Slower</td>
</tr>
<tr>
<td>Sensitivity to changed sediment loads</td>
<td>High</td>
<td>Lower</td>
</tr>
<tr>
<td>Variation in bed material size</td>
<td>Small</td>
<td>Large</td>
</tr>
</tbody>
</table>
Perception Issues

- Location of urbanization relative to the channel network and observation location
- Interplay of timing of development, large storms, lag time, and field observations
- Hydraulic structures
- Rate of sediment depletion from hillslopes and channel sources
- Use of “bankfull” indicators
- Stream type
- Historical influences

Imperviousness & Stream Stability
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Urban Stream Quality

Changes in Urban Stream Quality

- Sediment pulses during construction
- Pollutant load a function of imperviousness
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Changes in Urban Stream Quality

• Bacteria present in wet and dry weather
• Higher metals and hydrocarbon levels

Changes in Urban Stream Quality

• Higher stream temperatures

Vs.
Changes in Urban Stream Quality

• Trash and floatables present

What Can We Do?
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Plan …
Analyze…
Design…
Construct…
Educate/Communicate!

Plan

• Modify subdivision/development regulations
• Provide credits for “cluster” developments
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Analyze

• Develop detailed watershed models for water quantity and quality

Analyze

• Evaluate regional detention opportunities
Design

- Design to fit the site
- Design BMPs to address quantity and quality
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Construct

• Bio-retention swales

Construct

• Porous Pavement
Construct

• Overflow parking

Construct

• Fire department access
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Construct

- Integrated/innovative detention facilities that meet tree ordinances and green space requirements

Educate
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Hazard and Risk

\[
\text{HAZARD (FREQUENCY & SEVERITY)} \times \text{RESOURCES EXPOSED TO HAZARD} = \text{RISK (DOLLARS)}
\]

- Probability of Damage
- Value and Vulnerability of Resource Exposed to Hazard
- Severity of Threat to the Built & Natural Environment

Conclusions

- Increases in runoff volumes must be addressed to reduce impacts on urban drainage systems:
  - Channel degradation
  - Flooding
  - Drainage system performance.
- There is a direct correlation between increased imperviousness and impacts to stream hydrology, stream geomorphology, and urban stream water quality.
- There are proven techniques to mitigate these impacts.
- We must do a better job of educating the practitioners and the public.
- Recent natural disasters have shown the need to consider hazard and risk in our analyses.
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In Closing …

Scale, environment and uncertainty may be the three themes that are central to understanding the problems of prediction of morphological changes in unstable channels. … Often attached to the results [of simulation models that are physically based and distributed] is a spurious impression of accuracy which should remind us that these models, whilst they may be used for predictive purposes, may be little more than tools for probing the depths of our uncertainty.

Richards and Lane (1997)
Questions and Discussion