Modeling Low Impact Development Features at the Watershed Scale Using a Distributed Hydrologic Model

Civil and Environmental Engineering
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Research Questions

- Are LID features beneficial as flood control/management measures?

- If so, what types and configurations of LID features would be required to achieve optimal flood reduction in the areas of concern?

- Since LID features are usually simulated at the parcel-scale, is it possible to represent the effects of LID at the watershed scale?
The Woodlands, TX

- Northwest of Houston, TX
- Located within the Spring Creek watershed
- Over 97,000 residents
- 6,000 acres of green space

Source: www.thewoodlands.com
**Vflo™ Overview**

- Fully distributed physics-based hydrologic model
  - Spatially-derived variables: soil properties, land use/cover, elevation data

- Infiltration based on Green and Ampt Equation

- Runoff is routed from grid cell to grid cell
  - Finite Element Method
  - Kinematic Wave

- Precipitation input as rain gage data or radar rainfall
Vflo™ Inputs

- Land Use
- Soils
- DEM
- Vflo™ Model

Developed by Vieux, Inc.

Doubleday et al. 2012
Vflo™ Grid

Flow Characteristics

- Overland
- Channel
- Direction

Infiltration Excess Calculated at Each Cell

- Rainfall Rate
- Infiltration Rate
- Runon From Upslope
Model Development and Calibration

- Previously built by George Doubleday
  - 22,400 cells with 200x200 ft grid resolution
  - 5 m resolution DEM
  - 30 m resolution soil data

- 1974 “undeveloped” model
  - 30 m 1983 landuse/land cover
  - Calibrated to three 1974 storms

- 2006 “current development” model
  - 30 m 2006 landuse/land cover
  - Calibrated to 2008 and 2009 storms

- Hypothetical “fully developed” model
1974 Rainfall Events over Current Development Conditions

- ~20% increase in peak flow
- Some shift in timing earlier
- Design of The Woodlands effectively minimizes the effects of development on hydrology
What if The Woodlands was fully developed?

- Cypress Creek *Vflo™* model used to estimate roughness and impervious values for Houston’s highly urbanized areas
  - Overland Roughness \((n)\) = 0.024
  - Imperviousness = 27%
- Changed channel roughness to 0.015 to represent a hypothetical concrete channel network
1974 Rainfall Events over Fully Developed Watershed

- ~260% increase in peak flow
- Significant shift in timing earlier
- Fully developed watershed drastically impacts hydrologic response
Simulating LID Features in \textit{Vflo}™

- **Green roofs**
  - Modify Manning’s roughness, \( n \) for low and high intensity residential landuse in ArcGIS to 0.04 (from 0.015)
  - Modify Green and Ampt infiltration parameters for residential areas to sandy loam
  - Decrease imperviousness of residential areas from 0.3 to 0.1

- **Grass swales**
  - Increase Manning’s roughness \( n \) at left and right banks of the channel to 0.04
  - Decrease imperviousness near channels

- **Stream restoration**
  - Increase channel roughness to 0.045 to mimic natural streams
Discharge at Sawdust Rd. for 1” SCS III Rainfall

Discharge (cfs)

Time

Undeveloped
Discharge at Sawdust Rd. for 1” SCS III Rainfall
Discharge at Sawdust Rd. for 1” SCS III Rainfall

Discharge (cfs)

Time

- Red: Undeveloped
- Grey: Current
- Blue: Fully developed
Discharge at Sawdust Rd. for 1” SCS III Rainfall

- **Undeveloped**
- **Current**
- **Fully developed**
- **Stream restoration**
Discharge at Sawdust Rd. for 1” SCS III Rainfall

- Undeveloped
- Current
- Fully developed
- Stream restoration
- Green roof

Discharge (cfs)

Time
Discharge at Sawdust Rd. for 1” SCS III Rainfall

Discharge (cfs)

Time
Discharge at Sawdust Rd. for 1” SCS III Rainfall

- Undeveloped
- Current
- Fully developed
- Stream restoration
- Green roof
- Grass swale
- LID combined
Observations

- Green roofs and swales appeared to reduce peak flows by lowering the overall volume while maintaining the shape of the hydrographs.

- The stream restoration scenario lowered the peak by slowing down discharge, while keeping the volume relatively constant.

- The hydrologic response for the combined LID scenario behaved similar to a detention pond.
Simulated Peak Flows (cfs) at Sawdust Rd.

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<tr>
<td>Fully developed</td>
<td>706</td>
<td>2556</td>
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<td>Stream restoration</td>
<td>576</td>
<td>2206</td>
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<td>515</td>
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<td>15280</td>
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<td>Swale</td>
<td>436</td>
<td>1892</td>
<td>15975</td>
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<tr>
<td>LID combined</td>
<td>361</td>
<td>1736</td>
<td>14820</td>
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Peak reduction (%) achieved:

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<th></th>
<th>1 in</th>
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<tbody>
<tr>
<td>Stream restoration</td>
<td>18.4%</td>
<td>13.7%</td>
<td>11.1%</td>
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<td>27.1%</td>
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<td>38.2%</td>
<td>26.0%</td>
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<td>LID combined</td>
<td>48.9%</td>
<td>32.1%</td>
<td>19.3%</td>
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Work in Progress

- Zoom in to a small ~5 mi² subwatershed and simulate individual parcels (50x50 ft grid cells) to better study the effects of LID features.

- Incorporate results into the larger model (200x200 ft grid cells) as inflow hydrographs or with adjusted parameters.
Work in Progress

- Simulate other LID features, e.g. rain barrels, porous pavement, and combinations thereof

- Compare hydrologic response of LID features to conventional flood control measures, such as reservoirs and detention ponds

- Investigate the cost/benefit of implementing either LID or conventional flood control measures, as well as the combination of both in new development and retrofit areas
Conclusions

• Retrofitting a fully developed watershed to mimic its predeveloped hydrologic condition would be very difficult with LID alone.

• The results show that LID features have flood reduction potentials, especially for the smaller storms.

• Implementing LID features early in new development is preferable, but there are benefits in retrofitting existing development with LID features.