Brief Overview of Landscape Evolution Models and their Application to West Valley

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Outline

1. Overview of landscape evolution models (LEMs)
2. Perspectives on erosion modeling at West Valley
3. Summary
Brief History

- 1940s and 50s: birth of quantitative landform analysis
- 1960s: USLE introduced. First geomorphic transport functions. Example: \( q_s = D S \)
- 1970s: first computer models of 3D landform evolution
- 1990s: modern generation of models

Some Current Models

Table 1: Partial list of numerical landscape evolution models published between 1991 and 2005

<table>
<thead>
<tr>
<th>Model</th>
<th>Example reference</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIBERIA</td>
<td>Wilgoose et al. (1991)</td>
<td>Transport-limited; introduces channel activator function</td>
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<tr>
<td>DRAINAL</td>
<td>Beaumont et al. (1992)</td>
<td>Fluvial transport based on &quot;undercapacity&quot; concept</td>
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<tr>
<td>GILBERT</td>
<td>Chase (1992)</td>
<td>Cellular automaton</td>
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<td>DELIM</td>
<td>Howard (1994)</td>
<td>Detachment-limited</td>
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<tr>
<td>GOLEM</td>
<td>Tucker and Slingerland (1994)</td>
<td>Introduces algorithms for neolith generation and landsliding</td>
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<tr>
<td>CASCADE</td>
<td>Braun and Sumbridge (1997)</td>
<td>Introduces irregular discretization method</td>
</tr>
<tr>
<td>CAESAR</td>
<td>Coulthard et al. (1997)</td>
<td>Cellular automaton algorithm for 2D flow field</td>
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<tr>
<td>ZSCAPE</td>
<td>Densmore et al. (1998)</td>
<td>Introduces stochastic bedrock landsliding algorithm</td>
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<tr>
<td>CHILD</td>
<td>Tucker and Bras (2000)</td>
<td>Introduces stochastic treatment of rainfall and runoff</td>
</tr>
<tr>
<td>EROS</td>
<td>Crave and Davy (2001)</td>
<td>Modified precipitation algorithm</td>
</tr>
</tbody>
</table>

Notes:
1. First reference in mainstream literature.

(source: Tucker and Hancock, in review)
Ingredients of a LEM

- Grid of cells
- Hydrology model
- Geomorphic transport functions for:
  - Water-driven sediment transport processes
  - Gravity-driven transport processes (hillslopes)
  - Other processes (e.g., weathering, vegetation)
- Initial and boundary conditions

Example of a Landscape Evolution Model

(quicktime movie)
Smooth and rough landscapes

- Roughening: growth of rills and gullies
  - Less vegetation, more runoff, more erodible soils
- Smoothing: soil creep
  - Rapid soil mixing by plants and animals, ice growth in soil, and other processes
Applications of Landscape Evolution Models

• Better understanding of surface processes and dynamics
• Design and decision-making for mine spoil engineering and reclamation
• Gully erosion analysis to support land management
• Fate and transport of heavy metals in sediments
• Sediment flux and storage in forested mountain drainage basins

Two examples

(Hancock et al., 2006)

(Stephen Lancaster, OSU)
Testing and Calibration

- Measured water and sediment yield
- Laboratory scale models
- Rapid landforms
- Natural experiments
- Field and lab tests of individual components (for example, soil creep)

Buttermilk Creek

- Evolution from reasonably well known initial condition following last glacial retreat
- Similar time scale to 10,000-year forecast window
- Sources of uncertainty include boundary conditions (past and future climate), initial conditions, materials, and constitutive laws
Perspectives on LEM application at West Valley

• “…SIBERIA predictions are so vastly different from the current topography, that … results should be rejected.”

• Excessive smoothness reflects choice of very large soil creep coefficient

• Recommendation: use nonlinear slope transport model to better capture rapid mass movement on steep slopes

Perspectives on LEM application at West Valley

• “… core issue of whether there is any defensible technical basis for conducting quantitative long-term erosion predictions with a certainty that would allow these predictions to be used in a License Termination Rule (LTR) compliance demonstration.”

• Ability of LEMs to model long-term landscape development can be tested by running forward-in-time simulations from post-glacial topography
How climate enters landscape evolution models

- Rainfall and runoff
- Soil creep rate
- Other factors (bedrock weathering, vegetation cover effects)

Perspectives on LEM application at West Valley

- “... model does not change properties as the stream channels reach elevations where they would intersect different geological materials.”
- CHILD has this capability
- To some extent, the importance of this issue will be tested by paleo-erosion modeling
- Seek to understand simple models first
Summary

- A LEM applies transport functions that iteratively shape a gridded representation of topography
- History of landscape evolution models dates back to 1960s (and conceptually to late 19th century)
- LEMs are being used to support environmental decision making in a variety of contexts
- Confirmation and testing derives from flux measurements, scale models, rapid landforms, and natural experiments
- Buttermilk Creek is a type of natural experiment; comparing predicted and observed post-glacial landform evolution might help reduce uncertainty