Modelling connectivity in landscapes – Linking morphological complexity and sediment connectivity

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Outline

- Linking morphological complexity and sediment connectivity
  - ESPL 38, 1457-1471 (2013)
- Verifying these modelling results....invitation to cooperate!
- Some questions / ideas / challenges!
Introduction

- **Connectivity**
  - Landscape: physical coupling of landforms
  - Hydrology: passage of water through a catchment
  - Sediment: transfer of sediment through a basin

Source: Fryirs et al., 2007
Introduction

- Factors that affect (sediment) connectivity:
  - Vegetation
  - Slope
  - Catchment size
  - Tectonics
  - Human impact
  - Morphology
  - Terraces
  - V-shaped
  - U-shaped
  - Alluvial fans
  - Rolling
  - Etc...
Objective

- Better understand and quantify the relationship between landscape morphological complexity and sediment connectivity:

Hypothesis:

Connectivity decreases with increasing landscape morphological complexity
Methodology

1. Index of a landscape’s morphological complexity
2. Index of sediment connectivity
3. Test catchments:
   - Virtual catchments
   - Real catchments
4. Landscape evolution model ‘LAPSUS’
Methodology – indices

1. Index of a landscape’s morphological complexity
   - Overall relief
   - Terrain roughness – slope variability
   - Stream network density
   - (Catchment shape; and many more)

   → Partial indices were standardized (0-1)
   → Average of the partial indices was taken as the complexity index

2. Index of sediment connectivity: SDR (sediment delivery ratio)

\[
SDR = \frac{\text{Net erosion}}{\text{Total erosion}} = \frac{\text{Total erosion} - \text{Total Deposition}}{\text{Total erosion}}
\]
Methodology – test catchments

- Virtual catchments:
  - 10 m resolution;
  - 200x501 cells (10 km$^2$)

- Examples:
  a. V-shaped without floodplain
  b. V-shaped with floodplain
  c. U-shaped
  d. One fluvial terrace
  e. Two fluvial terraces
  f. Three fluvial terraces
  g. Agricultural terraces, lower slopes
  h. Agricultural terraces, upper slopes
  i. Agricultural terraces, entire slope
Methodology – test catchments

- Real catchments:
  - 30 m SRTM resolution;
  - 400x400 cells (144 km$^2$);
  - common, typical morphologies

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a. V-shaped
b. U-shaped
c. Alluvial fan
d. Highly dissected
e. Fluvial terraces
f. Rolling
```
Methodology - model

4. Landscape evolution model ‘LAPSUS’
   ● Simulate the 3D development of landscapes
   ● Usually over longer timescales (decades – centuries – millennia)
   ● Cellular; catchment scale
   ● Several processes can, optionally, be included:
     ● Water erosion
     ● Tillage erosion
     ● Landslides
     ● Fluvial behaviour
     ● Creep
     ● Soil development
Results: virtual catchments

a. V-shaped without floodplain
b. V-shaped with floodplain
c. U-shaped
d. One fluvial terrace
e. Two fluvial terraces
f. Three fluvial terraces
g. Agricultural terraces, lower slopes
h. Agricultural terraces, upper slopes
i. Agricultural terraces, entire slope

Fig. 2: Erosion and deposition in the virtual catchment after a 200mm rain event

- Orange: Erosion
- Green: Deposition
- Yellow: No net change
Results: virtual catchments

- For the 200 mm catchment, the relationship is given by:
  \[ y = -17.5 \cdot \ln(x) - 2.03 \]
  with \( R^2 = 0.81 \).

- For the 150 mm catchment, the relationship is given by:
  \[ y = -16.8 \cdot \ln(x) - 15.5 \]
  with \( R^2 = 0.68 \).

- For the 100 mm catchment, the relationship is given by:
  \[ y = -16.0 \cdot \ln(x) - 13.0 \]
  with \( R^2 = 0.65 \).
Results: real catchments

Fig. 3: Erosion and deposition in the real catchments after a 200mm rain event
Results: real catchments
Discussion

- Hypothesis confirmed:
  - non-linear relation between sediment connectivity and landscape morphological complexity

- Validation of results: areas with similar external conditions but with different morphologies

- Limitations:
  - External conditions are not taken into account
    - E.g. vegetation, geology, soil depth, infiltration, sediment availability etc.
  - Hypothesis: these factors increase the differences between different landscapes even more

- Calculation of indices
  - Morphometrics
  - SDR
Verifying our results...invitation!

Does the relation between morphological complexity and connectivity also hold for real catchments?

Data needed...invitation to cooperate!

- Sediment yield and hydrographs at (sub)outlets
- Sediment Delivery Ratio
- Detailed DEM
- Climate (rainfall), land use/cover, soil type, vegetation etc.

Catchments that represent a specific typical landscape; or major forms should be easy to separate
Questions / ideas / challenges

- How to incorporate connectivity into models?
  - Implicitly/explicitly
  - **Emerging property**?

- How to ‘measure’ it (as model output)?
  - SDR as ‘proxy’? Better ideas...?

- Which resolution?
  - Spatial...landscape scale? Data availability
  - Temporal...rainfall events? Yearly? Within events?
Thank you!

...let’s continue the discussion!

*Based on:*
Baartman et al., 2013 - ESPL 38, 1457-1471
Conclusions

- Quantification of landscape morphological complexity and sediment connectivity

- Detailed insight into, and awareness of, the different behaviour and response of diverse morphologies to catchment processes, is useful for effective water, landscape and ecosystem catchment management
Results: virtual catchments

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Relief standardized</th>
<th>SV/S&lt;sub&gt;mean&lt;/sub&gt;</th>
<th>SV/S&lt;sub&gt;mean&lt;/sub&gt; standardized</th>
<th>Complexity index</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. V-shape</td>
<td>0.00</td>
<td>0.06</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>b. V-shape with floodplain</td>
<td>0.06</td>
<td>0.12</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>c. U-shape</td>
<td>0.01</td>
<td>0.40</td>
<td>0.28</td>
<td>0.14</td>
</tr>
<tr>
<td>d. One fluvial terrace</td>
<td>0.19</td>
<td>0.37</td>
<td>0.26</td>
<td>0.22</td>
</tr>
<tr>
<td>e. Two fluvial terraces</td>
<td>0.28</td>
<td>0.71</td>
<td>0.50</td>
<td>0.39</td>
</tr>
<tr>
<td>f. Three fluvial terraces</td>
<td>0.38</td>
<td>1.23</td>
<td>0.87</td>
<td>0.62</td>
</tr>
<tr>
<td>g. Agricultural terraces (lower half)</td>
<td>0.06</td>
<td>0.76</td>
<td>0.53</td>
<td>0.30</td>
</tr>
<tr>
<td>h. Agricultural terraces (upper half)</td>
<td>0.06</td>
<td>0.96</td>
<td>0.67</td>
<td>0.37</td>
</tr>
<tr>
<td>i. Agricultural terraces (entire slope)</td>
<td>0.06</td>
<td>1.43</td>
<td>1.00</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Results: real catchments

Table 5: Morphological complexity of the real catchments

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Relief standardized</th>
<th>$SV/S_{mean}$</th>
<th>$SV/S_{mean}$ standardized</th>
<th>Stream order standardized</th>
<th>Complexity index</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. V-shaped</td>
<td>0.00</td>
<td>1.09</td>
<td>0.61</td>
<td>0.37</td>
<td>0.33</td>
</tr>
<tr>
<td>b. U-shaped</td>
<td>0.17</td>
<td>1.42</td>
<td>0.80</td>
<td>0.60</td>
<td>0.52</td>
</tr>
<tr>
<td>c. Alluvial fan</td>
<td>0.45</td>
<td>1.21</td>
<td>0.68</td>
<td>0.95</td>
<td>0.70</td>
</tr>
<tr>
<td>d. Highly dissected</td>
<td>0.79</td>
<td>1.62</td>
<td>0.92</td>
<td>0.98</td>
<td>0.89</td>
</tr>
<tr>
<td>e. Fluvial terraces</td>
<td>0.92</td>
<td>1.77</td>
<td>1.00</td>
<td>1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>f. Rolling</td>
<td>0.90</td>
<td>1.46</td>
<td>0.83</td>
<td>0.38</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Discussion

- Hypothesis is confirmed:
  - Sediment connectivity decreases with increasing landscape morphological complexity
  - Non-linear relationship
  - Different for virtual and real catchments
    - Resolution
    - Complexity index calculation
    - Absence of fine-scale roughness in virtual DEMs
a. Virtual catchments

Net erosion \( (0.10^3 \text{ m}^3) \)

\[ y = -1715 \cdot \ln(x) - 744 \]
\[ R^2 = 0.78 \]

Complexity index

\[ y = 263 \cdot x^{0.86} \]
\[ R^2 = 0.98 \]

(a) V-shape
(b) V-shape with floodplain
(c) U-shape
(d) One fluvial terrace
(e) Two fluvial terraces
(f) Three fluvial terraces
(g) Agricultural terraces (lower half)
(h) Agricultural terraces (upper half)
(i) Agricultural terraces (entire slope)
b. Real catchments

\[ y = -1.4 \cdot 10^6 \cdot \ln(x) - 138857 \]
\[ R^2 = 0.90 \]

\[ y = -71152 \cdot \ln(x) - 9769 \]
\[ R^2 = 0.90 \]

(a) V-shaped
(b) U-shaped
(c) Alluvial fan
(d) Highly dissected
(e) Fluvial terraces
(f) Rolling