A plot tree structure to represent surface flow connectivity in rural catchments and facilitate landscape management and water protection

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• Agricultural landscapes are structured
  – by a mosaic of farmers’ fields whose land use change over time
  – by linear elements such as hedgerows, ditches and roads (boundaries, interface) which are more or less connected to each other and to the fields

• Such man-made features are now well known to have an effect on catchment hydrology, erosion and water quality, acting as sink or source

• In such agricultural landscapes, as necessary step for improving landscape design and water protection, it is crucial to have
  – an adequate representation of the flow pathways and
  – relevant indicators of surface flow connectivity over the catchment towards the stream
How to take into account the flow pathways and therefore identify critical source areas?
1. Method

Aurousseau P., Gascuel-Odoux C., et al., 2009

A plot drainage network as a conceptual tool for the spatialisation of surface flow pathways for agricultural catchments. 

*Computer and Geosciences, 35, 276-288.*
Identifying the inlets and outlets on each field

Estimating the relative areas contributing to any outlet

Inside one plot, hydrological areas are delineated regarding its outlets

Deducing a drainage network composed of a set of elementary plot outlet trees labelled by attributes, particularly surface areas
If present, linear networks such as roads, modify this tree structure, by adding functions:

- Wall: redirect the flow pathways
- Walls crossing or Sink: can isolate a part of catchment area

Applied for hedgerows and roads.

Road acts as a wall
Neural road
Road acts as a ditch
The global plot outlet tree represent a pattern of surface flow relationships and constitutes a landscape drainage network.
The global plot outlet tree represents the pattern of surface flow relationships over the catchment. Therefore, only a part of the surface area of the catchment is effectively connected to the stream. Entire or part of plots are disconnected.
Statistics on the plot connectivity

The small plot outlet trees are numerous
The great part of the surface area is composed of middle size plot outlet trees

This can be useful to compare different catchments
• This **landscape drainage network** greatly reduces the number of objects in comparison with a drainage network made up of pixels or DEM cells.

• It provides a simple and appropriate way of representing the surface flow connectivity from plot to plot over the catchment, which leads to a functional display of data for decision support.

• It allows us to highlight the plots of potential risk regarding surface runoff
2. Applications to identify critical source areas for erosion

Gascuel-Odoux C., et al., in review Hydrological Processes

A catchment presenting
- High baseflow erosion (40%)
- High density of hedgerows
- Grassland

Assumption: riparian erosion?

The hedgerow and road networks are highly developed, and therefore, reduce the effective contributing area to the stream.
When considering the land use
• Sink: on grassland and forested areas

Taking into account land use improve the identification of critical areas
<table>
<thead>
<tr>
<th>Attributes of tree structures</th>
<th>Based on the plan plot</th>
<th>Plus hedge and road network</th>
<th>Plus land use in 2006</th>
<th>Plus land use in 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of connected pixels</td>
<td>43955</td>
<td>23601</td>
<td>1960</td>
<td>2147</td>
</tr>
<tr>
<td>Number of connected plots</td>
<td>312</td>
<td>247</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Mean number of plot outlets per plot</td>
<td>6.61</td>
<td>3.84</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mean height of trees</td>
<td>3.82</td>
<td>2.72</td>
<td>1.53</td>
<td>1.65</td>
</tr>
<tr>
<td>Mean drainage area of trees (m²)</td>
<td>25174</td>
<td>14424</td>
<td>6125</td>
<td>5803</td>
</tr>
<tr>
<td>Cultivated areas</td>
<td>2008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>--------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(results in percent of the cultivated areas)</td>
<td>1.73km²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of hedge and road network</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially or totally connected plots</td>
<td>79.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected surface areas (pixels)</td>
<td>18.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of land use, hedge and road network</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially or totally connected plots</td>
<td>27.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected surface areas (pixels)</td>
<td>7.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The connected areas are low extended (7% of the surface area) and close to the stream, indicating that the suspended sediment comes from riparian areas in this catchment.

Some upslope plots are connected to the stream by the way of artificial areas which can play a major role in connecting upslope arable areas.

We can easily identify the hot points of source of erosion: they are not numerous.
3. Modelling surface runoff and pollutant fluxes

Gascuel-Odoux C, Cordier MO, et al., 2009
A decision-oriented model to evaluate the effect of land use and management on herbicide contamination in stream water. 
*Environmental modelling and software*

Modelling surface and subsurface flow
  - Stream Model (Plot outlet tree + soil surface conditions)
  - Topmodel (DEM + hydrological assumptions)

Coupling water and pollutant (here pesticides), crop growth model
  - Simple bio-physical models or expert rules
Map of the surface areas where the water table depth < threshold (1 m) at two dates

= Contributing areas by subsurface flow (preferential recharge to the shallow groundwater)
Map of surface areas with soil sealing
(\textit{soil surface conditions changing in time})

\[= \text{the } \textbf{potential} \text{ contributing area related to surface runoff}\]

These surface areas increase in time
Map of surface areas connected and disconnected to the stream

*Surface runoff can infiltrate on a part of the previous identified plots*

= the **effective** contributing areas related to surface runoff
4. Deduce expert rules and spatial patterns explaining pollutant fluxes

Trepos R., PhD


http://dx.doi.org/10.1007/11564096_41
Elaborate a large set of examples (simulations) 
Induce rules (attributes or spatial patterns) 

- Climate 
- Weeding strategy 
- Crop location & buffer zones 

Examples 
- Data climatic series 
- Chemicals Calendar,... 
- Spatial distributions 

Simulator 
- Decision model 
- Tranfer model 
  - Surface & Subsurface model 
  - Tree plot structure 
  - Topographic index 

Data base or expert 

- Rainfall, Temperature, PET 
- Date for sowing 
- Date and application rate for weeding 

- Daily fluxes and concentrations in herbicides 
- Input / output ratio over the period and the catchment 

Relevant attribute and spatial patterns
Two automatic learning methods have been tested.

**Method 1**: tree patterns are generated, based on inductive logic programming.
- 7 attributes per plot
  - Total amount of pesticides per plot
  - Contributing area of the outlet
  - Maize crop (true or false)
  - Buffer zone (true or false)
  - Slope of the plot
  - Topographic index (soil wetness)
  - Post or pre-emergence application

**Method 2**: the information contained in the trees are synthesized and attribute-value rules identified.
- 11 global attributes per tree
  - Total amount of pesticides
  - % of 2 types of chemical (Koc and half time)
  - % of pre-emergence applications
  - Total surface area of the tree
  - % of maize crop
  - Surface of the largest maize plot
  - % of buffer zone
  - Tree-structure depth
  - Elevation range of the tree structure
  - Pattern of the tree structure (long / width)

Large set of simulation results on plot outlet trees are used for induction processes.

Limited set of patterns and rules:
- Surface > 0.8 ha
- Maize = true
- Surface > 0.4 ha
- Corn = true
- Pesticide applied = 18g
- Surface = 0.3ha
- Corn = true
- Pesticide applied = 15g
- Surface = 1ha
- Corn = false
- Surface = 0.4ha
- Corn = false
- Surface = 0.9ha
- Corn = false
- Surface = 0.4ha
- Corn = true
- Pesticide applied = 25g
- Surface > 0.4 ha Maize = true
- Surface > 0.8 ha
- If maize crop > 50% AND Total quantity of pesticides > 55 g THEN high pesticides contamination
Plot outlet trees are explained by selected patterns and rules on a catchment view.

Interactive selection of patterns and rules

To help the decision making process, the learning methods are incorporated in a visualization tool.
Conclusions

Scale: test the interest at operational scale (50 km²)

Method: dynamic method, analysing the evolution of plot connectivity in time

A chain of tools for decision making in spatio-temporal processes
- Here applied to erosion and pesticide contamination
- Being developed for N (part 4) and P (all the 4 parts)