A framework to test multiple optimality principles in landscape evolution under river dynamics

GM7.1
EGU2013-4870

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(1) INTRODUCTION

MOTIVATION
Techniques and knowledge for modeling landscape evolution under river dynamics are fundamental to assess their resilience to extreme events, climate change, and to improve planning and management strategies.

OBJECTIVE
Assess whether a **multi-objective framework** is suitable to test simplified formulations of Least Action Principle (LAP, see section 2) and model the 3D structure of landscapes and river.

CHALLENGES
- Would the framework be able to reproduce the 3D features of river networks (elevation, slopes and river longitudinal profile)?
- Are different formulations of the LAP are conflicting? Why?

On the left: V-shaped valley, Riobamba (Ecuador). On the right: U-shaped valley, Glen Geusachan (UK)

(2) LEAST ACTION PRINCIPLE

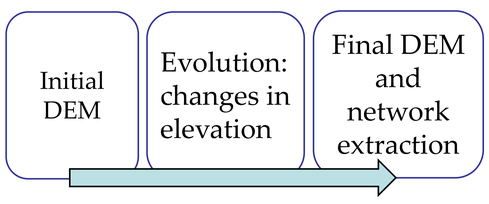
"The river channel has the possibility of internal adjustment among hydraulic variables to meet the requirement for maximum probability, and these adjustments tend also to achieve minimization of work."[1]

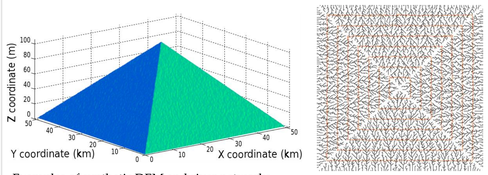
ADVANTAGE
Simpler than phisically based models, when applied at a basin scale.

PROBLEM
Its mathematical formulation is complicated, since the degrees of freedom are too many.
Therefore, many simplified versions were proposed, according to different studies needs.

(3) PREVIOUS ATTEMPT by Paik [2]

APPROACH
Single objective Genetic Landscape Evolution (GLE).





Examples of synthetic DEM and river networks.

FEATURES AND COMMENTS
- Single objective optimization.
- Good results for 2D networks, but limitations in reproducing slopes (third dimension) .

(4) A NEW FRAMEWORK

FEATURES
- **MULTI-OBJECTIVES OPTIMIZATION.**

- Four chosen criteria:

1. Minimum Total Energy Expenditure in the network as a whole:

$$\mathrm{TEE} = \min\left(\sum_{i=1}^{N} Q_i^{0.5} L_i\right)$$

2. Minimum Energy Expenditure in any link of the network:

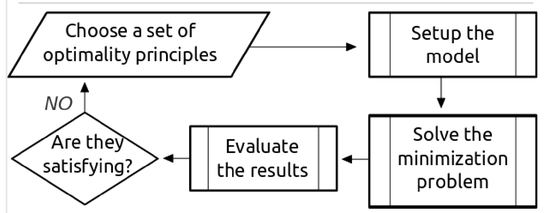
$$\mathrm{EEL} = \min\left(\mathrm{var}(\mathbf{Q^{0.5}L})\right)$$

3. Minimum Energy Expenditure:

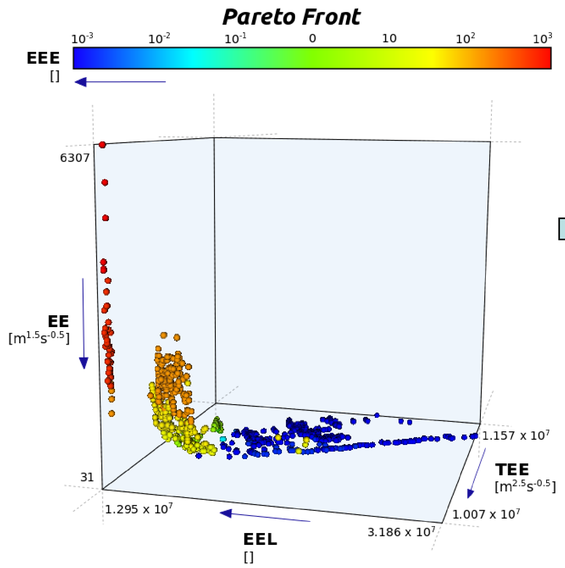
$$\mathrm{EE} = \min\left(\sum_{i=1}^{N} Q_i^{0.5} S_i\right)$$

4. Equal Energy Expenditure:

$$\mathrm{EEE} = \min\left(\mathrm{var}(\mathbf{Q^{0.5}S})\right)$$



(5) THE PARETO FRONT AND OTHER RESULTS

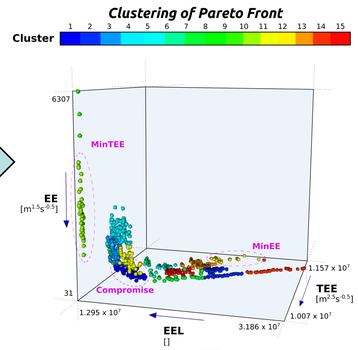


PARETO FRONT
- Each point is an optimized landscape.
- Each point is balancing in a different way the four objectives.

Conflict
The front shows conflicting objectives:
TEE and **EEL** are conflicting with **EE** and **EEE**.

Interpretation
Trade-offs among objectives should be interpreted in terms of different features of landscapes and river networks.

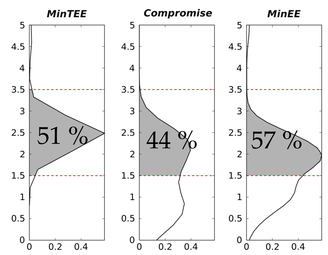
k-means clustering
Clustering technique allows to identify areas of the front with similar objectives.



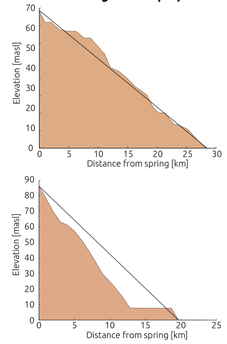
3 cluster are selected for comparing their landscapes to natural ones and see the trade-offs:

- **MinTEE**
  It minimizes objective **TEE** value, but is not optimal for **EE** objective.
- **Compromise**
  It minimizes a balanced weighted combination of **TEE** and **EE** objective.
- **MinEE**
  It minimizes objective **EE** value, but is not optimal for **TEE** objective.

Naturality indexes comparison for selected clusters
Comparison through Horton's and Hack's laws allows to understand if the trade-offs among objectives mirror in different features of landscapes and river networks.



Gray area is the probability of having slopes index in the natural range



Longitudinal river profiles, for MinTEE cluster (on top) and MinEE cluster (on bottom of figure)

USEFUL HINTS

A solution is called nondominated, Pareto optimal or efficient if none of the objective functions can be improved in value without impairment in some of the other objective values.

Objectives are conflicting if the fulfillment of one of them is in contrast with the fulfillment of one or more of the others.

DISCUSSION
- Slope is better reproduced than in past attempts (they were able to reproduce only the 2D structure of river networks).
- Promising results are obtained for the reproduction of longitudinal river profiles.
- Powerful tool for analyzing the trade-offs among formulations of the LAP.
  It improved the reproduction of synthetic landscape comparable to natural ones with respect to 3D features.

(6) FURTHER RESEARCH

- Inclusion of time dimension in the framework.
- Enforce the theoretical interpretation of the conflict among objectives.
- Foster applications of the model on real DEMs as case studies.
- Improve the model features (like DEM surface interpolation and depression filling algorithm).

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European Geosciences Union
General Assembly 2013