Identifying Sources of Eroded Sediment Using a Bayesian Framework

B. Abban[1], A.N. (Thanos) Papanicolaou[1], F. Jiao[2] and M.K. Cowles[2]

[1]Department of Civil and Environmental Engineering, The University of Iowa

[2]Department of Statistics and Actuarial Science, The University of Iowa

Background

* The United States Environmental Protection Agency estimates that over 17% of the nation's rivers are impaired due to the presence of excessive amounts of sediment.
* Knowledge of the sources of eroded sediment allow watershed managers to devise mitigation strategies that make efficient use of available resources by targeting the critical areas that contribute the most to erosion within a watershed.
* Land-use fingerprinting provides a means of identifying and quantifying the contributions of different land uses (sources) to in-stream sediment through the use of tracers and statistical un-mixing models.

A headwater stream in the Clear Creek watershed, Iowa

Study Objectives

* To extend the predictive capabilities of an existing statistical un-mixing model.
* To incorporate uncertainties in user knowledge of erosion processes into the model.
* Application of the improved model to a real watershed in Iowa.

Statistical Un-mixing Model

Original framework

* Proposed by Fox & Papanicolaou (2008).
* Bayesian, Markov Chain Monte Carlo framework.

Key parameters

* Erosion process parameter - represents the processes that contribute to erosion within the watershed.
* Episodic parameter - represents the intermittent nature of erosion.

Shortfalls of original framework

* Knowledge of the dominant erosion processes is unlikely to be known beforehand.

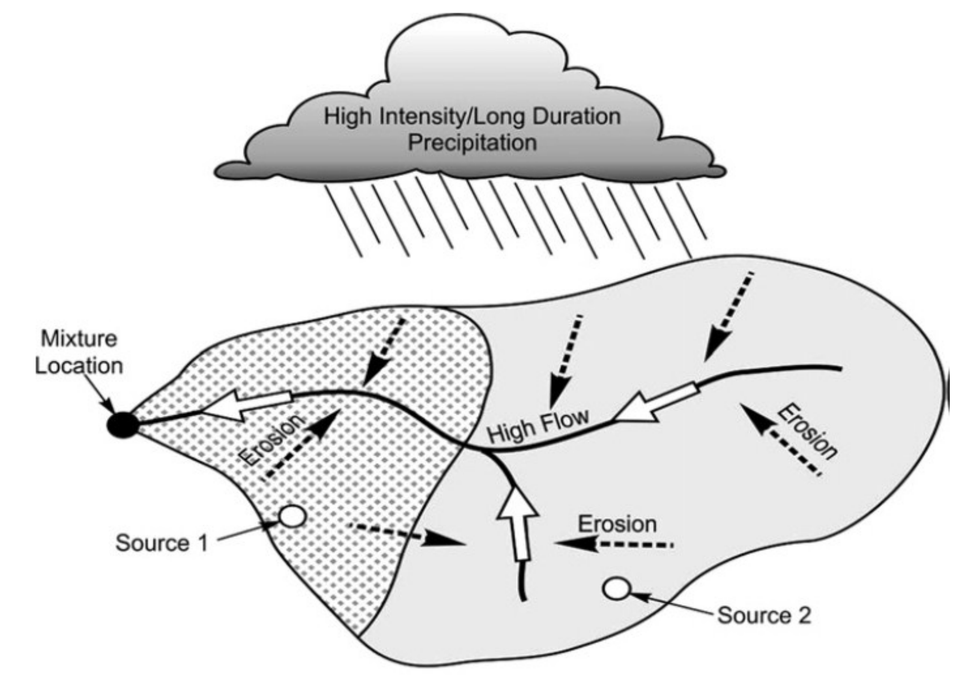
Modifications thus far

* Representation of the erosion process parameter with a Dirichlet distribution.

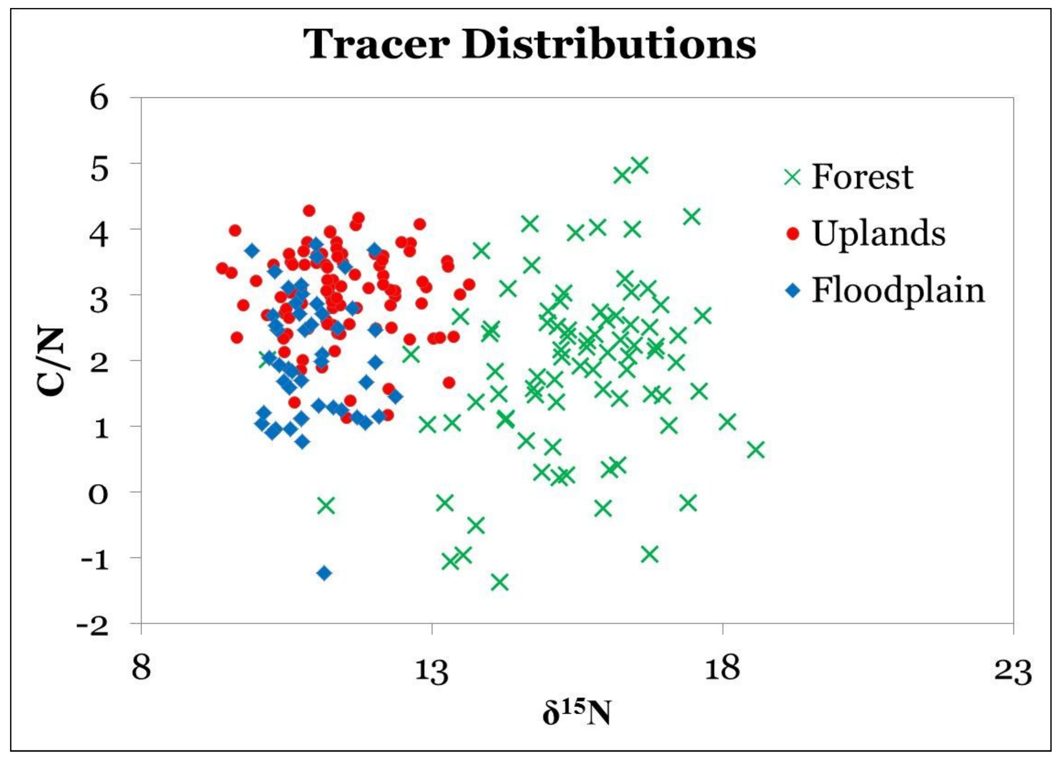
Model Application

Overview

* Different erosion scenarios for a hypothetical watershed were simulated.
* The watershed comprised forest and agricultural land uses.
* The agricultural land uses were divided into upland and floodplain regions.
* Rill erosion was assumed to occur on the uplands whilst gulley erosion was assumed to occur on the floodplains.



Source: Fox & Papanicolaou (2008)



Land-use Tracer Data

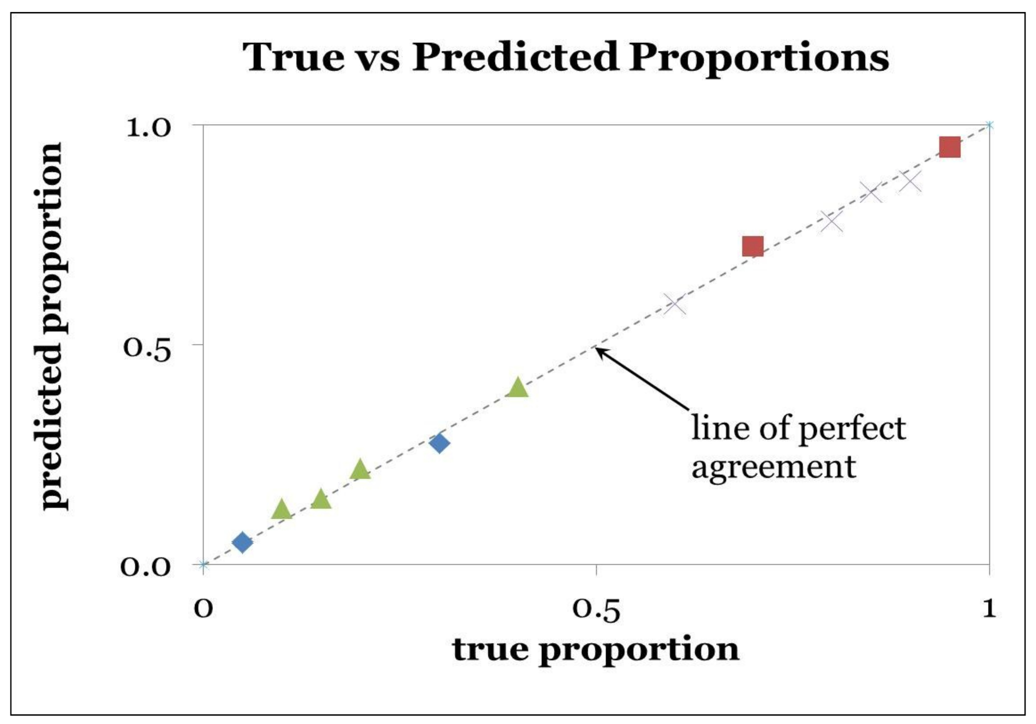
* Observed biogeochemical tracer distributions from the Jerome Creek watershed in Idaho were used to tag the soils in the hypothetical watershed.
  * Stable Nitrogen Isotope ($\delta^{15}N$)
  * C/N Ratio

Eroded Sample Data

* Tracer values of eroded samples at the watershed outlet were obtained by integrating randomly sampled tracer values from the Jerome Creek land-use distributions.

Results

* The model was able to adequately predict the relative contributions of the different land uses to in-stream sediment.
* The model was also able to provide information on which erosion processes were dominant. i.e. the proportion of erosion from rills (uplands) and the proportion of erosion from gulleys (floodplains).
* Fairly small 95% credible sets were obtained, indicating little uncertainty in the predicted results.



Conclusions and Discussion

* Improvements to the model have made it possible to obtain information on the dominant erosion processes that occur within a watershed.
* The improved model accommodates uncertainties in user knowledge about the governing erosion processes.
* Field-based methods like the one presented generally require a considerable set of sampled data. Nevertheless, they are effective means of quantifying the contributions of different sources to eroded sediment in rivers.
* Biogeochemical Tracers are environmentally friendly and provide a sustainable means of identifying soil sources.

Model Description

Input Requirements

* Tracer signature distributions of each land use source in the watershed.
* Tracer signatures of time-integrated eroded samples collected at the watershed outlet.

Output

* Proportion of eroded sample originating from each land use.
* Credible sets of predicted proportions.

Basic Bayesian Formulation

Land-use Tracer Distributions:

$$x_{ij} \sim \mathrm{MVN}(\mu_{ij}, \Sigma_{ij})$$

x_{ij}—signature of i^{th} tracer for j^{th} land-use

μ_{ij}—mean signature of i^{th} tracer for j^{th} land-use

Σ_{ij}—covariance matrix

Un-mixing formulation:

$$Z_i \sim \mathrm{MVN}(\varphi_i, \Gamma_i)$$

$$\varphi_i = \Sigma\, x_{ij} P_j$$

$$P_j \sim \mathrm{Dirichlet}(\lambda_j)$$

P_j— proportion of eroded sample from j^{th} land-use

Z_i— i^{th} tracer signature of eroded sample

φ_i— mean i^{th} tracer signature of eroded sample

Γ_i— covariance matrix

λ_j— parameter vector

In-stream sampling of eroded sediment at watershed outlet

Future work

* Accommodation of uncertainty in user knowledge of the episodic nature of erosion.
* Application of the model to a watershed in Iowa.

References

Fox, J.F. and Papanicolaou, A.N. 2008. An un-mixing model to study watershed erosion processes. *Advances in water resources*, 31, 96 - 108.

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