A comparison between riverbank erosion models with an evaluation of the risk

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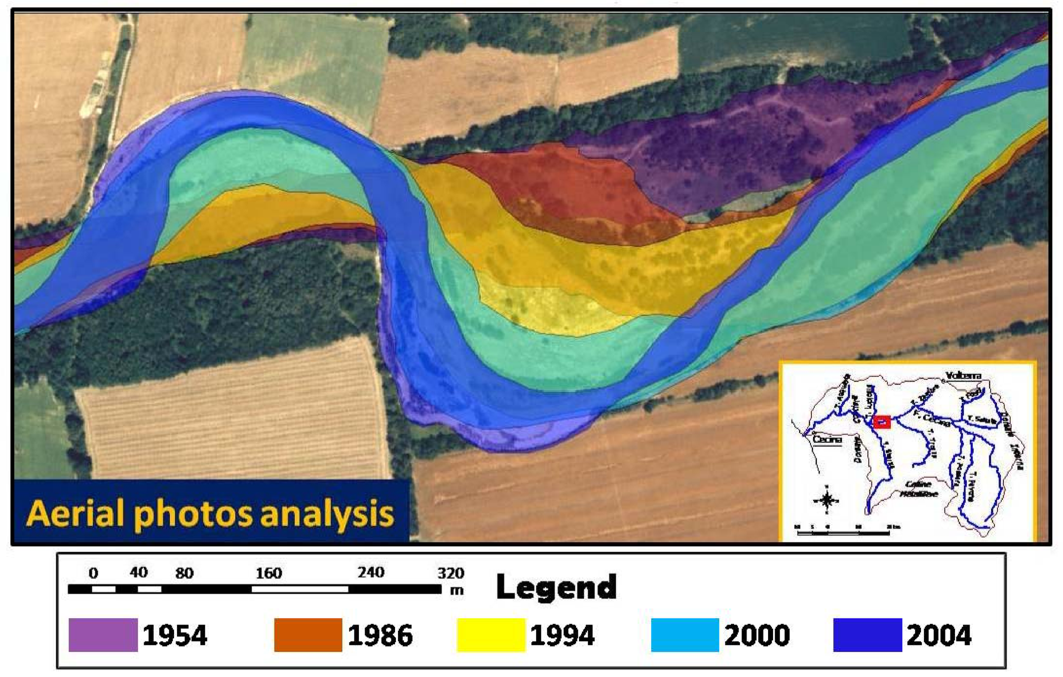
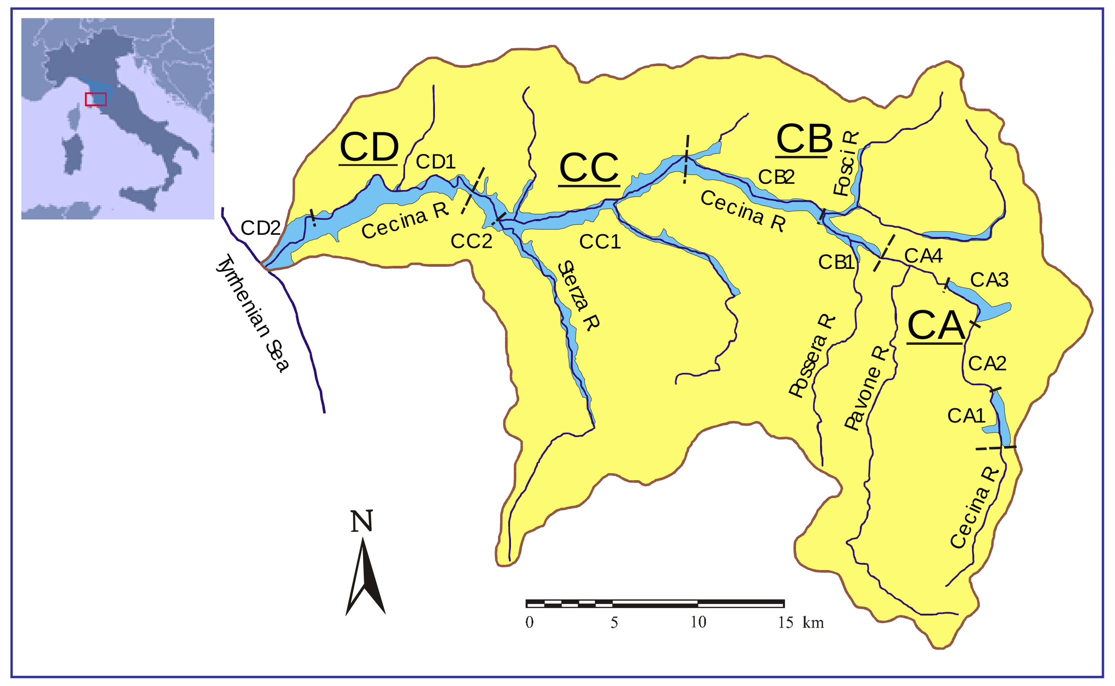
1. The case study

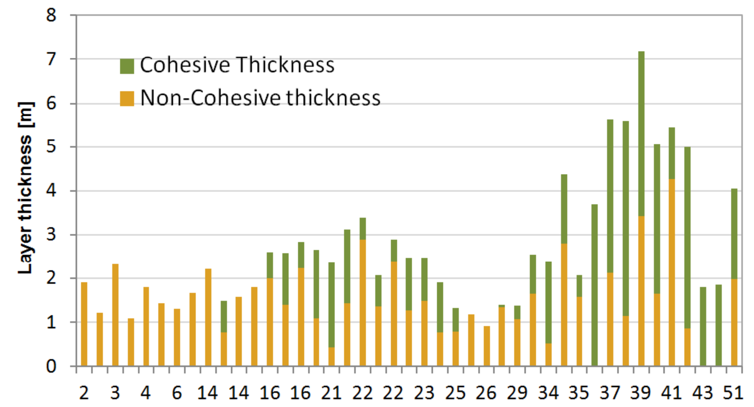
The estimation of the river bank erosion requires the knowledge of both local hydrodynamic and erodibility characteristics. Models exist in literature that allow to estimate the river bank shear stress, the fundamental parameter in evaluating the retreat given the discharge flow and the geometry of the river channel. In this work two hydrodynamic models (1-D and 2-D) were combined with three shear stress models in order to obtain an estimation of the retreat on a study case on the river Cecina in Tuscany, Central Italy.



Channel evolution in the period 1954 - 2004

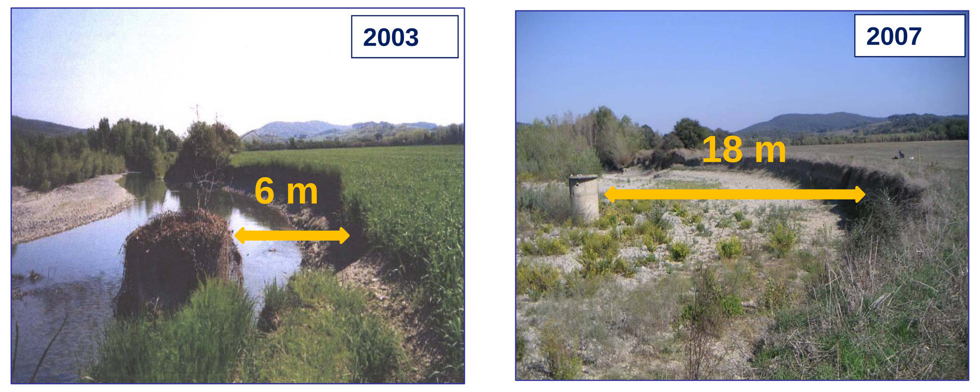


Location of the Cecina river basin in Central Italy.



Surveyed riverbanks

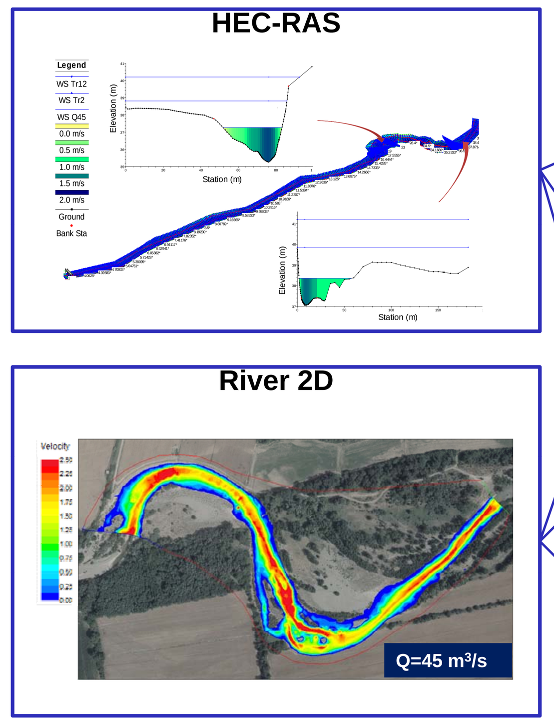
Riverbanks along the Cecina

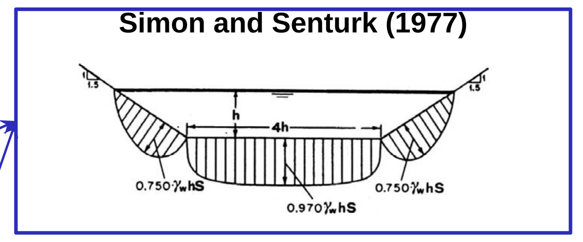


Riverbank retreat in the period 2003 -2007 at the study reach

2. Models

Three different models were tested for the computation of the near-bank shear stress: the empirical distribution from Simon and Senturk (1977), the computing scheme of the River2D hydrodynamic model, and the analytical model from Kean and Smith (2006a).

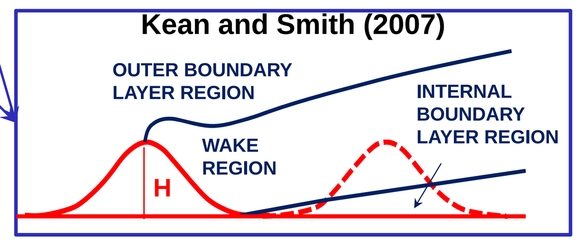




River 2D

$$C_S = 5.75 \log_{10}\left(12\frac{H}{k_s}\right)$$

$$\tau = \rho \frac{|U|^2}{C_S^2}$$



- **STEP 1: DATA COLLECTION** — GPS, Grain size distribution, CSM, Bank roughness
- **STEP 2: HYDRODYNAMIC MODELLING** Q: 5⇒ 671.2m³/s — 1D Model → 2D. Model
- **STEP 3: NUMERICAL IMPLEMENTATION** — Near-bank shear stress (KEAN AND SMITH, 2006)
- **STEP 4: NEAR-BANK SHEAR STRESS ANALYSIS AND ERODIBILITY PARAMETERS CALIBRATION** — Comparison of results from models and calibration of erodibility parameters
- **STEP 5: COUPLING FLUVIAL EROSION AND BANK STABILITY ANALYSIS** (at 2 representative banks) — River2D-K&S + BSTEM
- **STEP 6: FRAMEWORK FOR FLUVIAL EROSION RISK ANALYSES** — Excess shear stress (Partheniades, 1963)

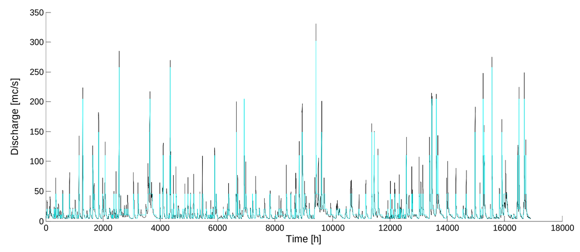
3. Calibration of erodibility parameters

A calibration of the models was performed basing on observations from aerial photos on the region in a period of ten years (1994-2004) and the results of the different combination of the models are discussed and compared.

INPUT DATA

1. **Measured bank retreat** (GIS on aerial photos)
2. **Flow events between 1994-2004** Step Hydrograph

Shear stresses along the bank for each discharge in the hydrograph and for each hydr. model



Riverbank retreat		
Frame-Time	M1 [m]	V1 [m]
1994-2000	11 ± 2.1	12.5 ± 2.1
2000-2004	19.5 ± 1.5	1 ± 1.5
1994-2004	30.5 ± 1.3	13.5 ± 1.3

ESTIMATED RATE OF RETREAT $\varepsilon = k_d(\tau - \tau_c)^a$ (Partheniades, 1963)

1994-2004

Section	Hydr. Mod.	Shear Stress Mod.	t_{c_g} [Pa]	K_{d_c} [m³ Ns⁻¹]	K_{d_g} [m³ Ns⁻¹]	Error [m]
M1	HR	SS	5.61	5.07E-07	1.07E-06	< 0.5
M1	HR	KS	5.59	5.24E-07	1.38E-06	< 0.5
M1	R2D	R2D	5.67	2.42E-07	6.85E-06	< 0.5
M1	R2D	KS	5.65	4.04E-07	2.75E-05	< 0.5
V1	HR	SS	-	-	-	-
V1	HR	KS	4.39	2.89E-08	6.47E-07	< 0.5
V1	R2D	R2D	-	-	-	-
V1	R2D	KS	4.09	2.58E-07	7.06E-05	< 0.5

1994-2000

Section	Hydr. Mod.	Shear Stress Mod.	t_{c_g} [Pa]	K_{d_c} [m³ Ns⁻¹]	K_{d_g} [m³ Ns⁻¹]	Error [m]
M1	HR	SS	5.56	7.25E-07	1.15E-06	< 0.5
M1	HR	KS	5.41	6.70E-07	1.54E-06	< 0.5
M1	R2D	R2D	5.64	1.41E-07	9.41E-06	< 0.5
M1	R2D	KS	5.61	1.01E-08	4.59E-05	< 0.5
V1	HR	SS	4.96	6.78E-08	3.54E-07	< 0.5
V1	HR	KS	4.56	2.92E-07	2.25E-06	< 0.5
V1	R2D	R2D	2.72	7.22E-07	2.57E-04	< 0.5
V1	R2D	KS	4.23	5.03E-07	2.93E-04	< 0.5

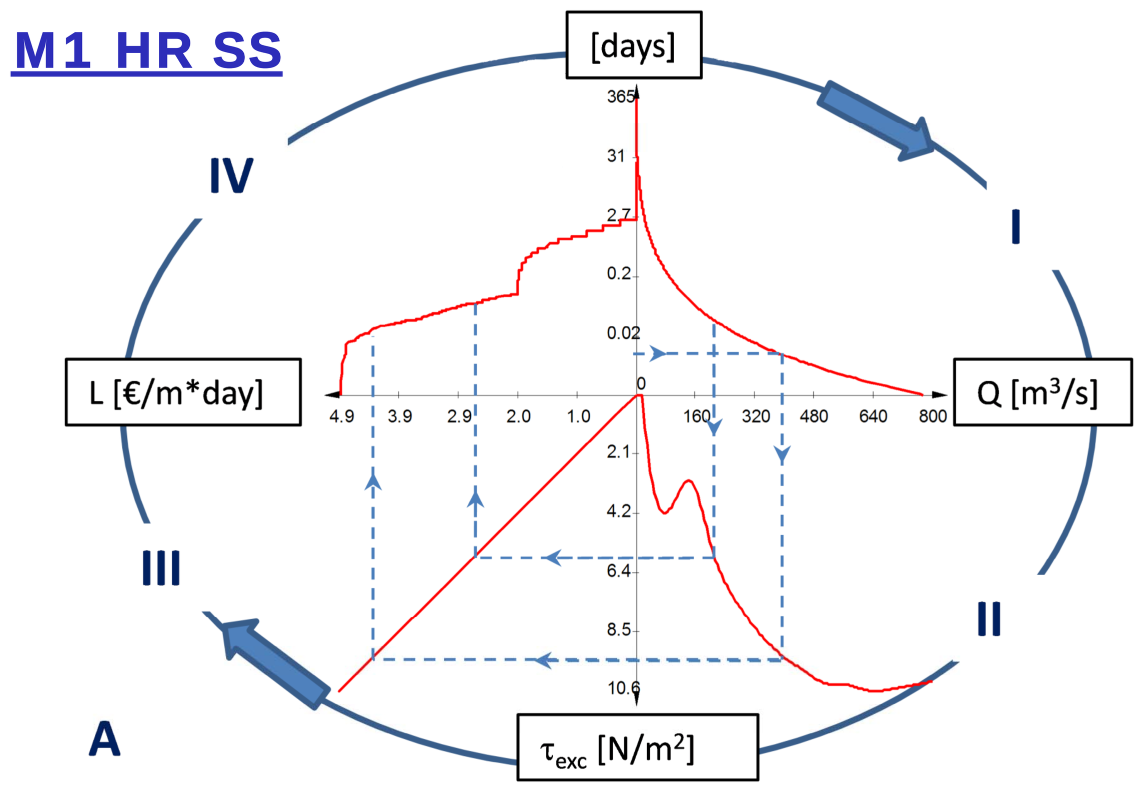
2000-2004

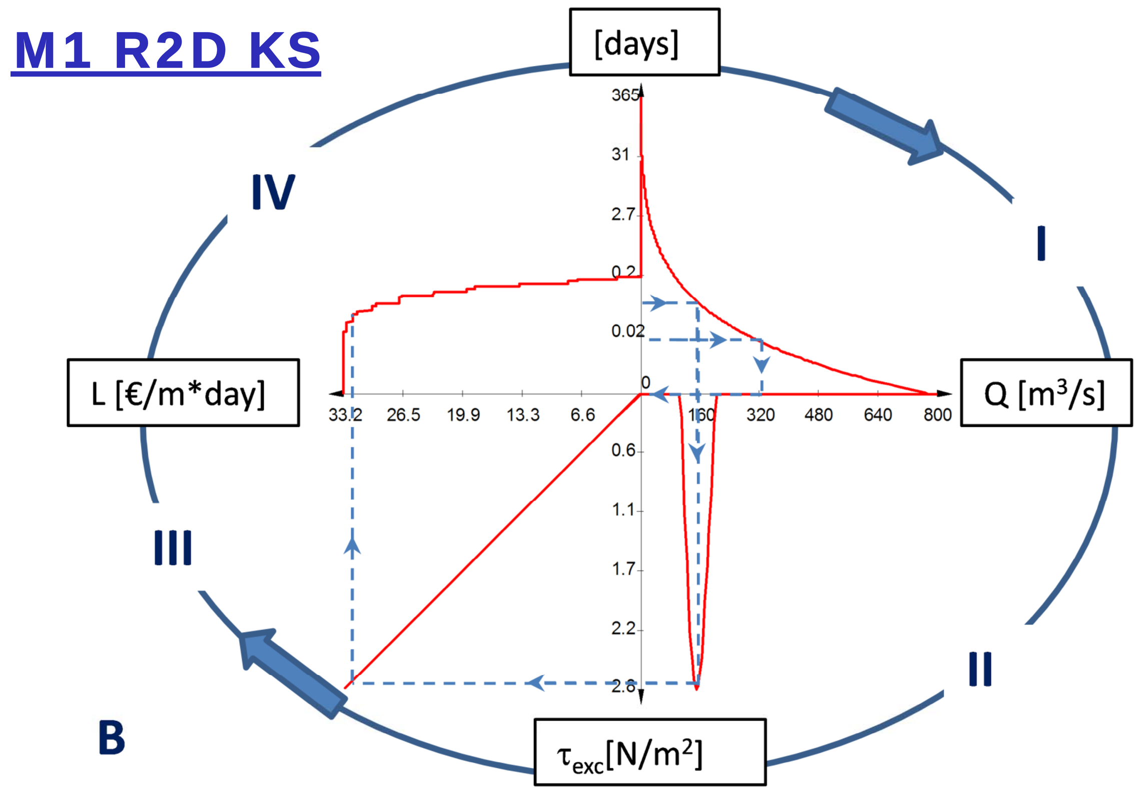
Section	Hydr. Mod.	Shear Stress Mod.	t_{c_g} [Pa]	K_{d_c} [m³ Ns⁻¹]	K_{d_g} [m³ Ns⁻¹]	Error [m]
M1	HR	SS	5.74	4.05E-08	1.08E-06	< 0.5
M1	HR	KS	5.71	9.71E-07	1.33E-06	< 0.5
M1	R2D	R2D	5.67	7.54E-07	5.92E-06	< 0.5
M1	R2D	KS	5.64	3.02E-07	2.17E-05	< 0.5
V1	HR	SS	29.13	2.89E-07	3.53E-07	< 0.5
V1	HR	KS	8.01	7.36E-08	1.26E-07	< 0.5
V1	R2D	R2D	4.5	1.12E-07	3.72E-06	1.06
V1	R2D	KS	4.28	4.28E-07	9.03E-06	< 0.5

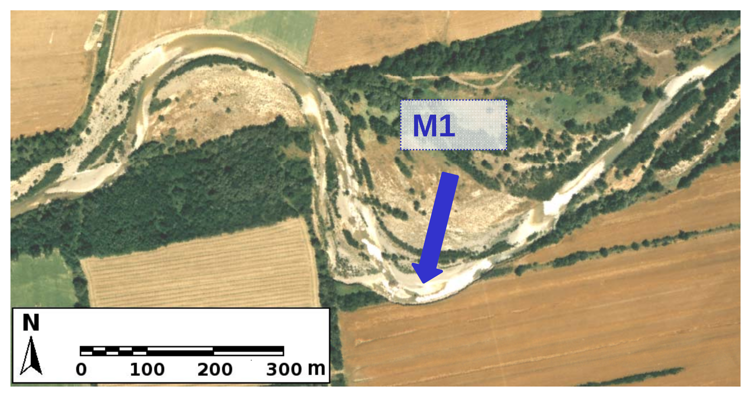
HR=HEC-RAS; R2D=River2D; SS=Simon and Senturk (1977); KS= Kean and Smith (2006a)

4. Evaluation of the risk

A framework was developed for risk analysis of land loss due to bank erosion, and an application to the study case is provided by using the results of fluvial erosion modeling.







Location of bank M1 at the study reach

I. Computation of Flow duration curve

II. Estimation of near-bank shear stress for each value of discharge

III. Application of fluvial erosion model for each value of bank shear stress

$$\varepsilon = k_d(\tau - \tau_c)^a$$

IV. Computation of *local loss duration curve*

$$R = \int_0^{1\,year} L dt$$

L (LOSS)= Bank retreat x Price of land [€/m·day]