Evaluating luminescence as a sediment transport metric

Harrison Gray[1,2], Gregory Tucker[1], Shannon Mahan[2]

University of Colorado Boulder

USGS science for a changing world

ACS PRF

Photo credit: ImageStock

Photo credit: Fisher-Price Fun-2-Learn Computer Cool School

Fine sediment transport in rivers

- The rates of fine sediment transport is an important variable in landscape evolution, river engineering, and restoration.

- Obtaining long-term rates (~10^4 year) are useful to place short-term (1-10^2 year) rates in context.

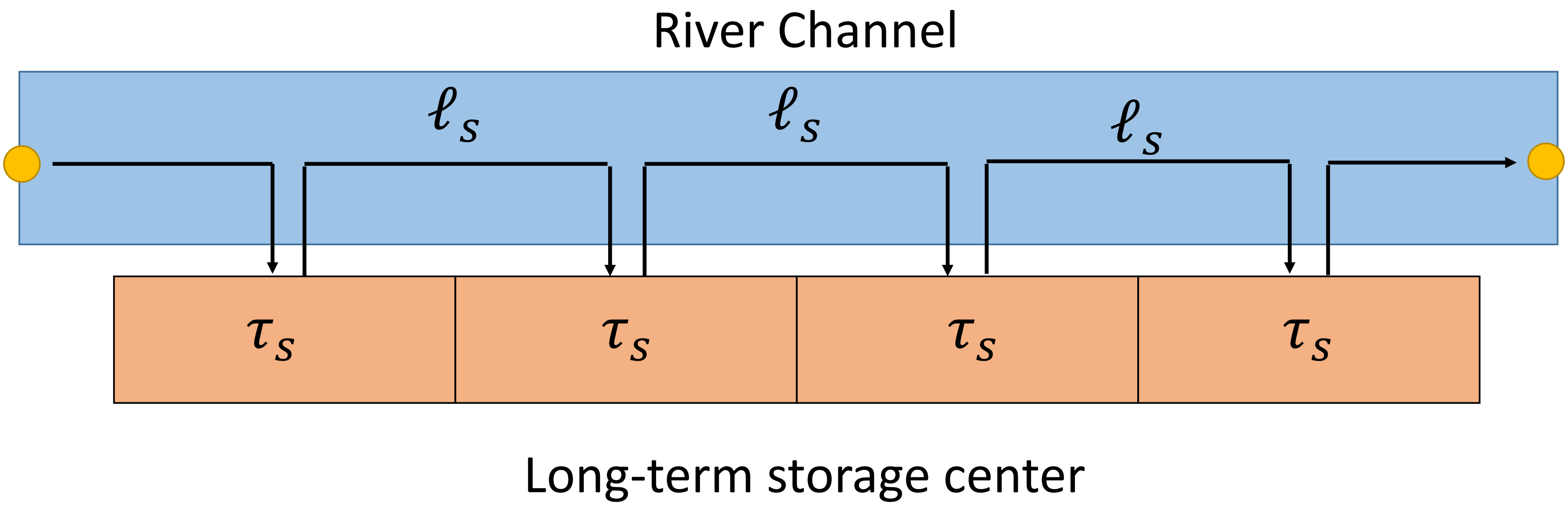
- Obtaining this data is difficult!

Lake Mills Reservoir, Elwa River, WA

Also, rivers are bullies

Sediment transport information

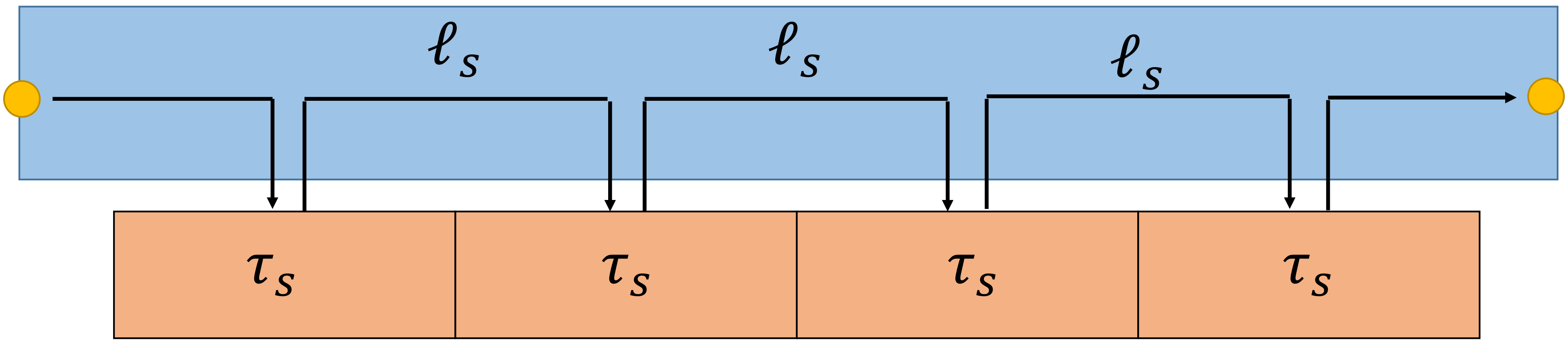
ℓ_s = characteristic transport lengthscale τ_s = characteristic storage timescale



Martin and Church, 2004; Lauer and Willenbring, 2010; Pizzuto et al., 2014

Sediment transport information

$$\overline{U} \approx \frac{\ell_s}{\tau_s}$$ = 'virtual velocity' of sand grains

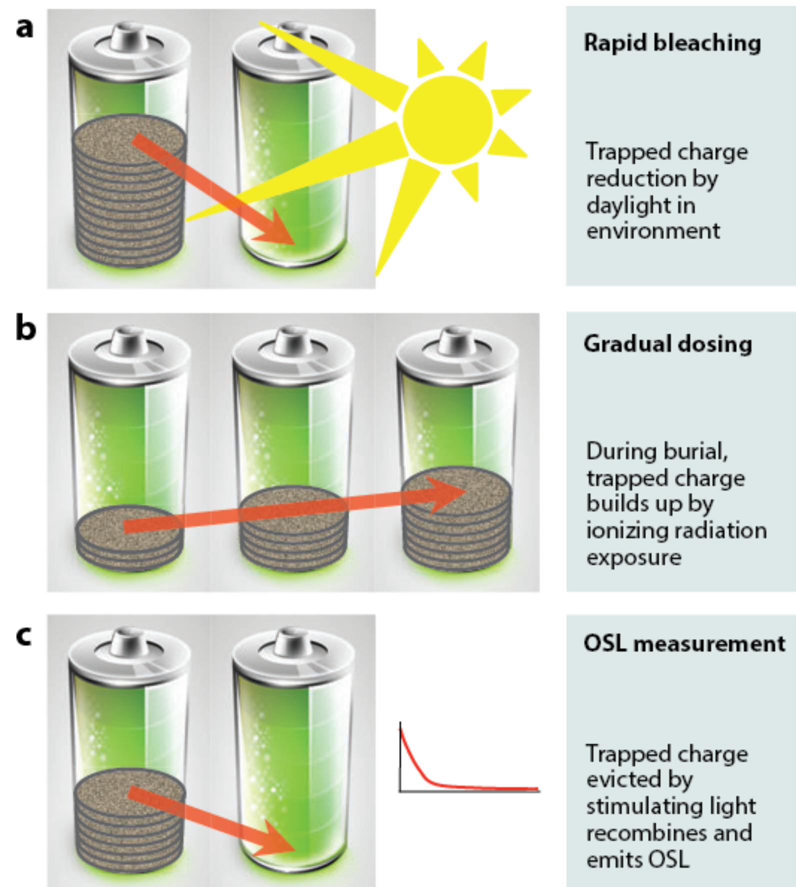


Long-term storage center

Martin and Church, 2004; Lauer and Willenbring, 2010; Pizzuto et al., 2014

Luminescence in solids

- Luminescence is a property of solids where light is produced from electrons “trapped” in crystal lattice defects.
- These electrons become trapped with exposure to background radiation and escape these traps when given energy through sunlight.

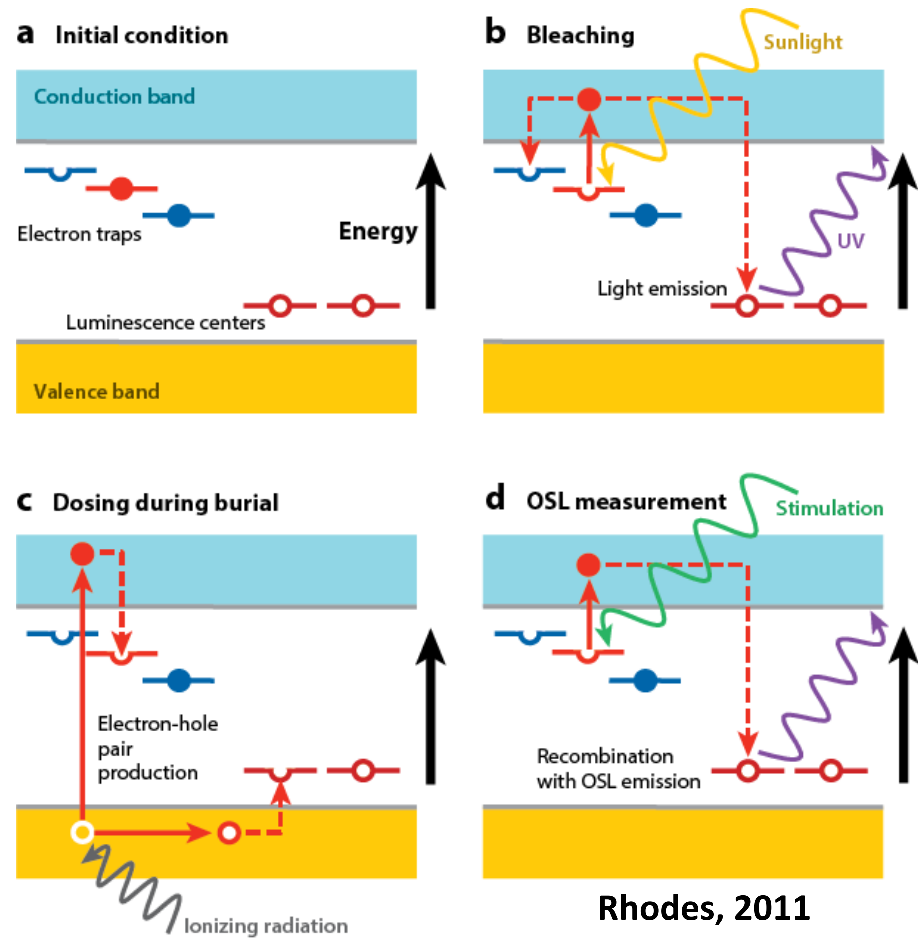


Rhodes, 2011

Luminescence in solids

- Luminescence is a property of solids where light is produced from electrons “trapped” in crystal lattice defects.

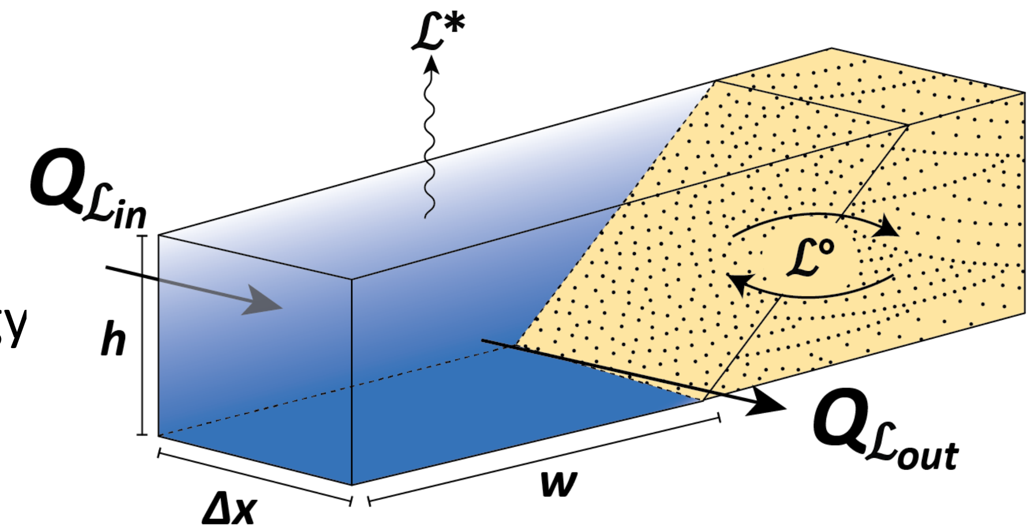
- These electrons become trapped with exposure to background radiation and escape these traps when given energy through sunlight.



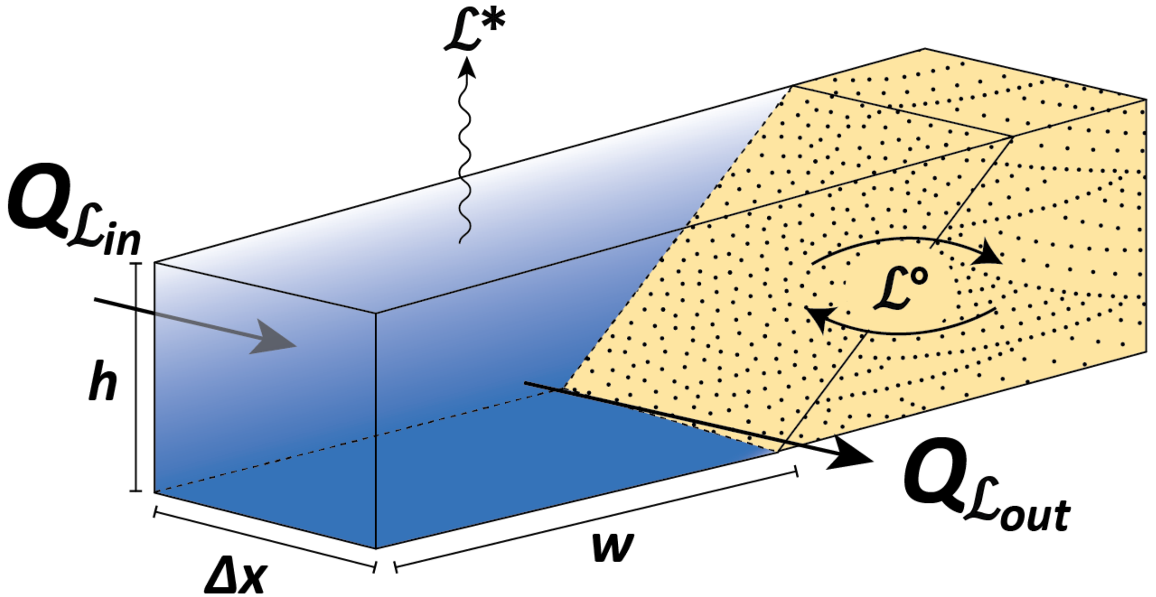
Rhodes, 2011

Modeling

- Model built from "conservation of luminescence"
- Essentially a simultaneous conservation of mass and energy
- Flux of luminescence-bearing material is delivered from upstream and from interactions with floodplain storage



(Gray et al.,2017)



$$\frac{\partial N_e}{\partial t} = Q_{L\,upstream} - Q_{L\,downstream} - Q_{L\,bleaching} - Q_{L\,deposition} + Q_{L\,entrainment}$$

$N_e = \Delta xwhC\mathcal{L}\rho$ $Q_{bleaching} = \Delta xwhC\mathcal{L}^*\rho$ $Q_{upstream} = whuC\mathcal{L}(x)\rho$ $Q_{deposition} = \Delta xwhf_D C\mathcal{L}\rho$

Q_{entra} $C\mathcal{L}(x+\partial x)\rho$

$\varphi(\lambda) = \varphi_o(\lambda)e^{-\frac{z_{eff}}{z_*(\lambda)}}$

$\frac{\partial(q_s\mathcal{L})}{\partial t} = u$

OH GOD

$q_s\mathcal{L} + f_E q_s\mathcal{L}_b$ $D_E(t) = ((\beta-1)k_t t + D_0^{1-\beta})^{\frac{1}{1-\beta}}$

$q_s\frac{\partial\mathcal{L}}{\partial t} + \mathcal{L}\frac{\partial q}{\partial t}$

$I(t) = ((\beta-1)ft + I_0^{1-\beta})^{\frac{1}{1-\beta}}$

$-k_z z(t)\ \partial z$

$\mathcal{L}^*{}_{fluvial} = \frac{\partial D_E}{\partial t} = -k_t D_E{}^{\beta} = -k_t\mathcal{L}^{\beta}$ $\frac{\partial D_E}{\partial t} = \frac{\partial I}{\partial t}($

$\left[\frac{z}{h-z}\frac{h-z_0}{z_0}\right]^R$

$\tau_s = \int_0^\infty t_s p(t_s)dt_s$ $\mathcal{L}_b = D_R(x,t)\cdot\tau_s$ $\frac{\partial\mathcal{L}_b}{\partial}$

PLEASE NO

$\mathcal{L}(x) = \mathcal{L}_0 e^{-\frac{k+\eta}{u}x} + \mathcal{L}_b\left[\frac{1-e^{-\frac{k+\eta}{u}x}}{1+\frac{k}{\eta}}\right]$ $\mathcal{L}^*(x) = e$

η

It simplifies!!!!

Two terms: first is a exchange term, second is a bleaching / advection term

$$\frac{\partial \mathcal{L}}{\partial x} = \eta_{km}(\mathcal{L}_b - \mathcal{L}) - \frac{\kappa}{u}\mathcal{L}^{\beta}$$

η is the amount of sediment exchanged with a storage center per unit distance

$\mathcal{L}_b$ is the luminescence of the storage center

$\mathcal{L}$ is the luminescence in the channel

κ, β are parameters describing bleaching

u is the velocity of sediment in the channel

It simplifies!!!!

$$\frac{\partial \mathcal{L}}{\partial x} = \frac{\eta}{u}(\mathcal{L}_b - \mathcal{L}) - \frac{\kappa}{u}\mathcal{L}^{\beta}$$

By measuring the other parameters, we can solve for u and η

$$\ell_s = \frac{u}{\eta} \qquad \overline{U} \approx \frac{\ell_s}{\tau_s}$$

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Earth Surface

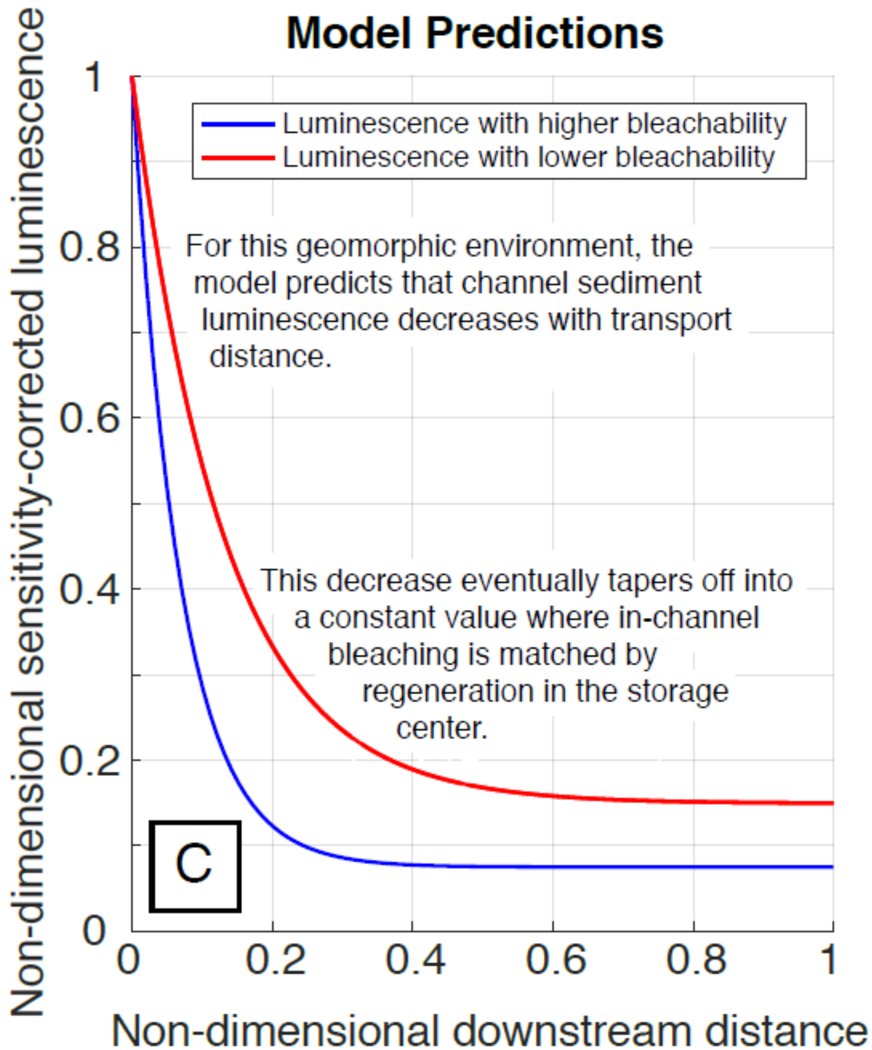
RESEARCH ARTICLE
10.1002/2016JF003858

Key Points:
- We develop a model coupling transport of fine sand and luminescence to explain the patterns of luminescence observed in river sediment
- The model successfully reproduces the patterns of luminescence measurements in two river systems
- Best fit values from the model describe sediment transport for fine sand, although our observed range is

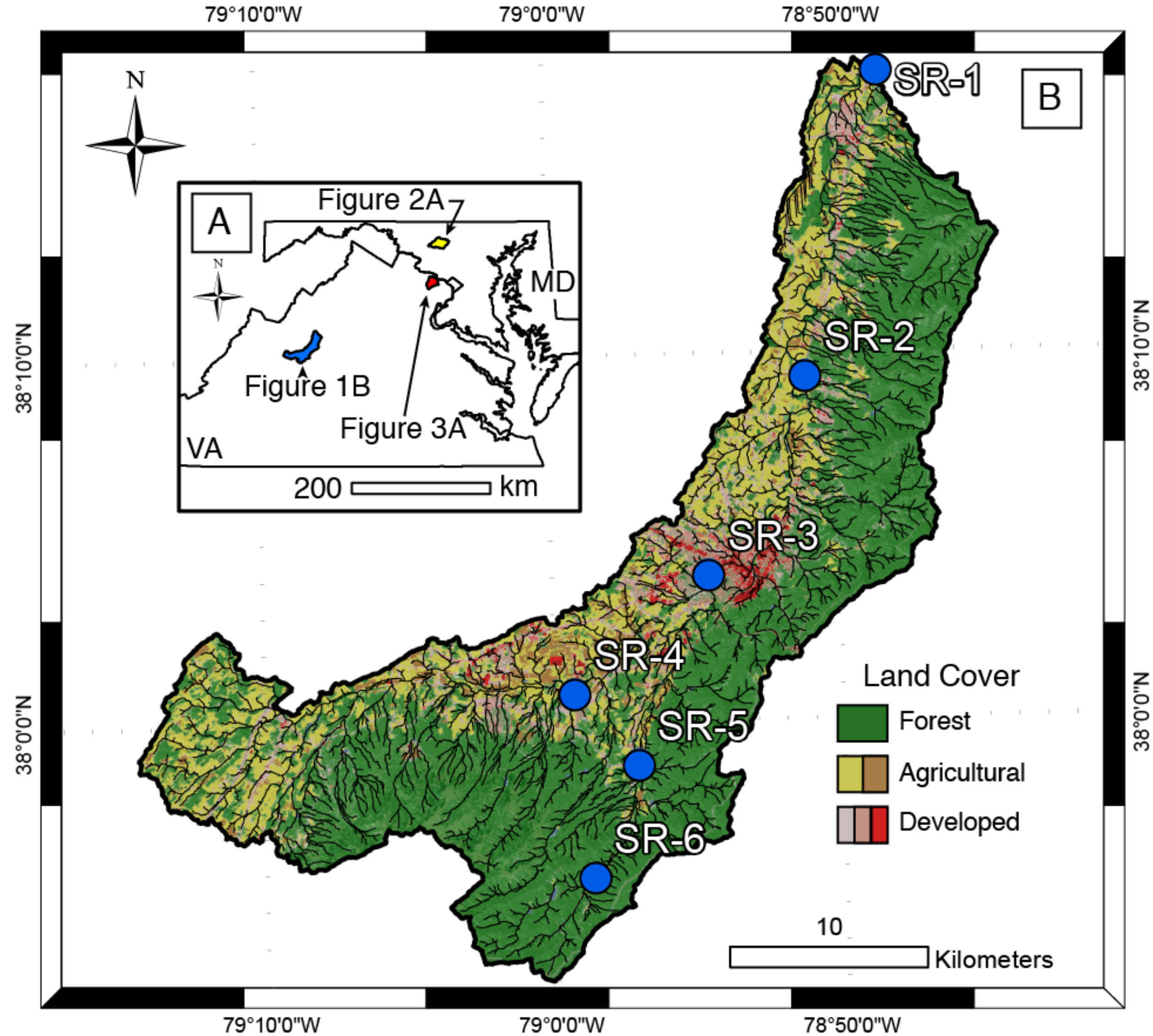
On extracting sediment transport information from measurements of luminescence in river sediment

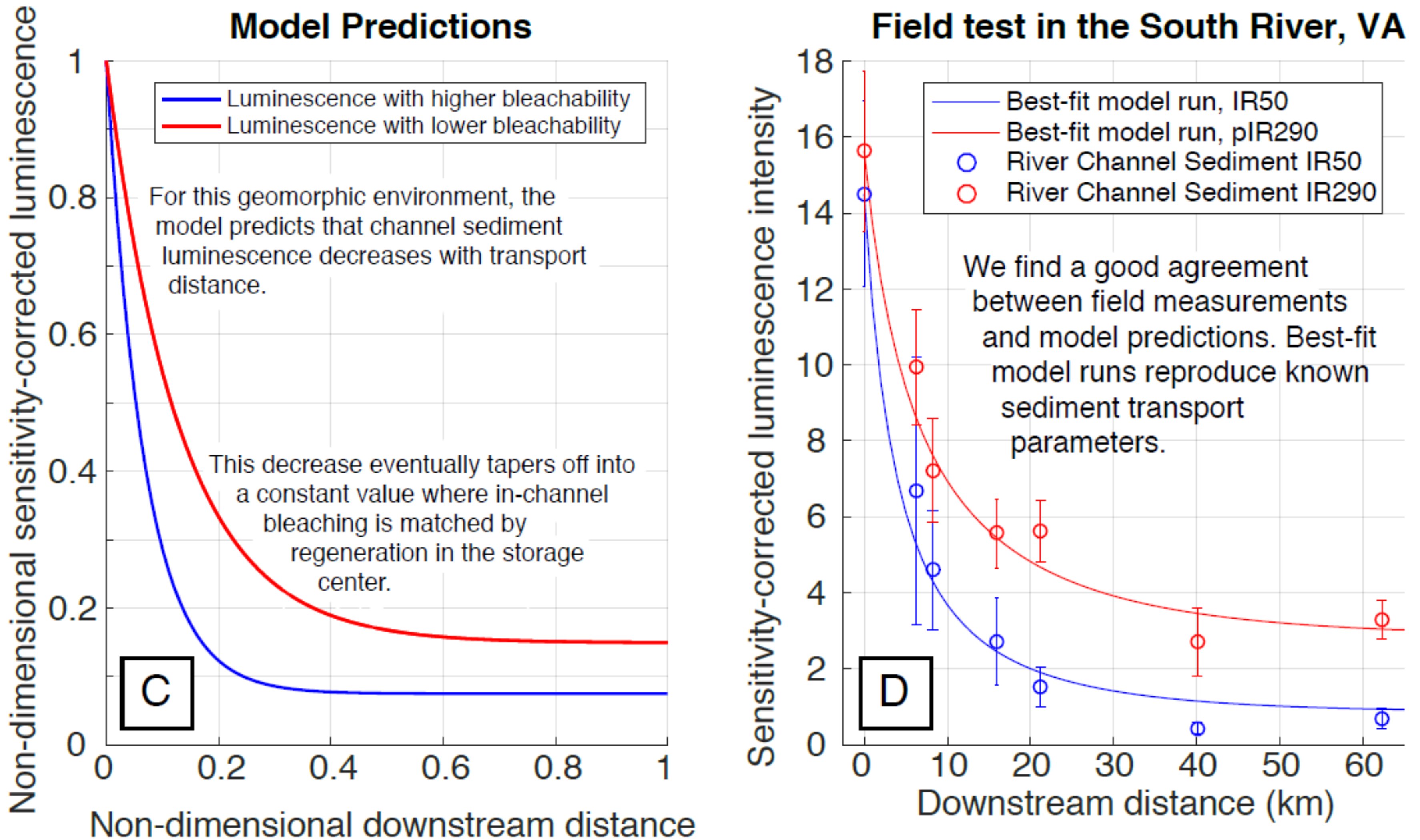
Harrison J. Gray[1,2], Gregory E. Tucker[1], Shannon A. Mahan[2], Chris McGuire[3], and Edward J. Rhodes[3,4]

[1]Cooperative Institute for Research in Environmental Sciences and Department of Geological Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [2]U.S. Geological Survey Luminescence Geochronology Laboratory, Denver Federal Center, Denver, Colorado, USA, [3]Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, California, USA, [4]Department of Geography, University of Sheffield, Sheffield, UK



Model Predictions
Luminescence with higher bleachability
Luminescence with lower bleachability
For this geomorphic environment, the model predicts that channel sediment luminescence decreases with transport distance.
This decrease eventually tapers off into a constant value where in-channel bleaching is matched by regeneration in the storage center.
C
Non-dimensional sensitivity-corrected luminescence
Non-dimensional downstream distance
0
0.2
0.4
0.6
0.8
1


79°10'0"W
79°0'0"W
78°50'0"W
SR-1
B
N
A
Figure 2A
MD
Figure 1B
Figure 3A
VA
200 km
SR-2
38°10'0"N
SR-3
SR-4
Land Cover
Forest
Agricultural
Developed
SR-5
38°0'0"N
SR-6
10
Kilometers

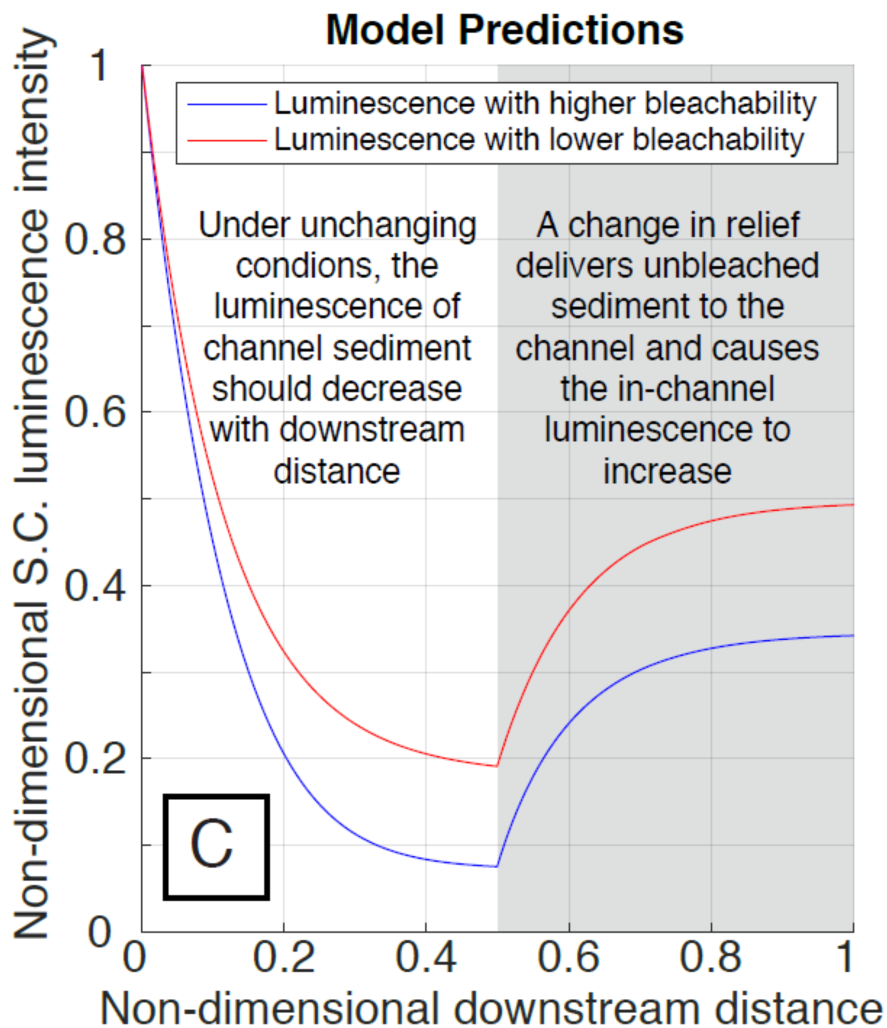


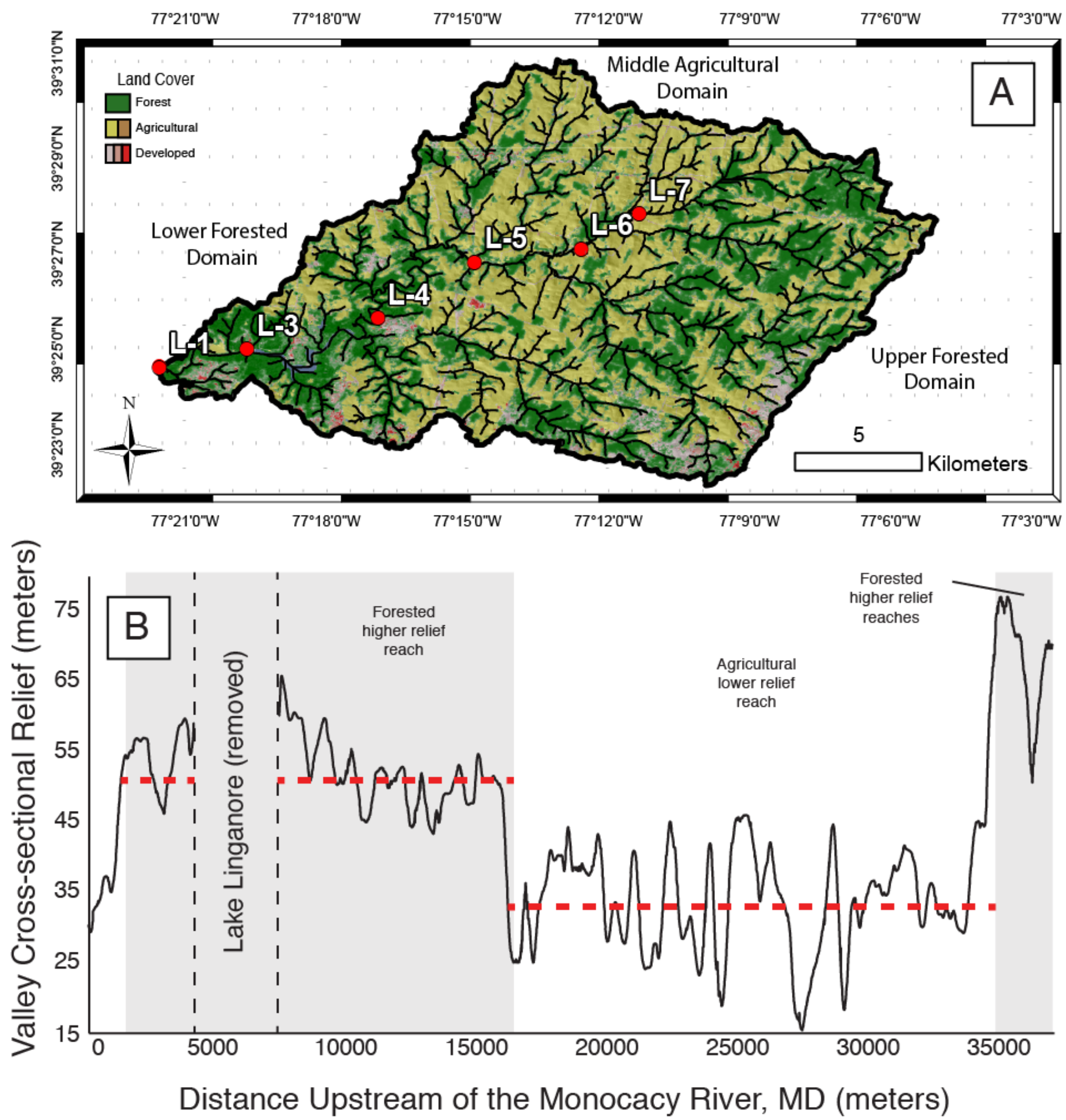
Model Predictions
Luminescence with higher bleachability
Luminescence with lower bleachability
For this geomorphic environment, the model predicts that channel sediment luminescence decreases with transport distance.
This decrease eventually tapers off into a constant value where in-channel bleaching is matched by regeneration in the storage center.
C
Non-dimensional sensitivity-corrected luminescence
Non-dimensional downstream distance
Field test in the South River, VA
Best-fit model run, IR50
Best-fit model run, pIR290
River Channel Sediment IR50
River Channel Sediment IR290
We find a good agreement between field measurements and model predictions. Best-fit model runs reproduce known sediment transport parameters.
D
Sensitivity-corrected luminescence intensity
Downstream distance (km)

Table 1. Comparison of known and modeled sediment transport parameters for the South River, VA.

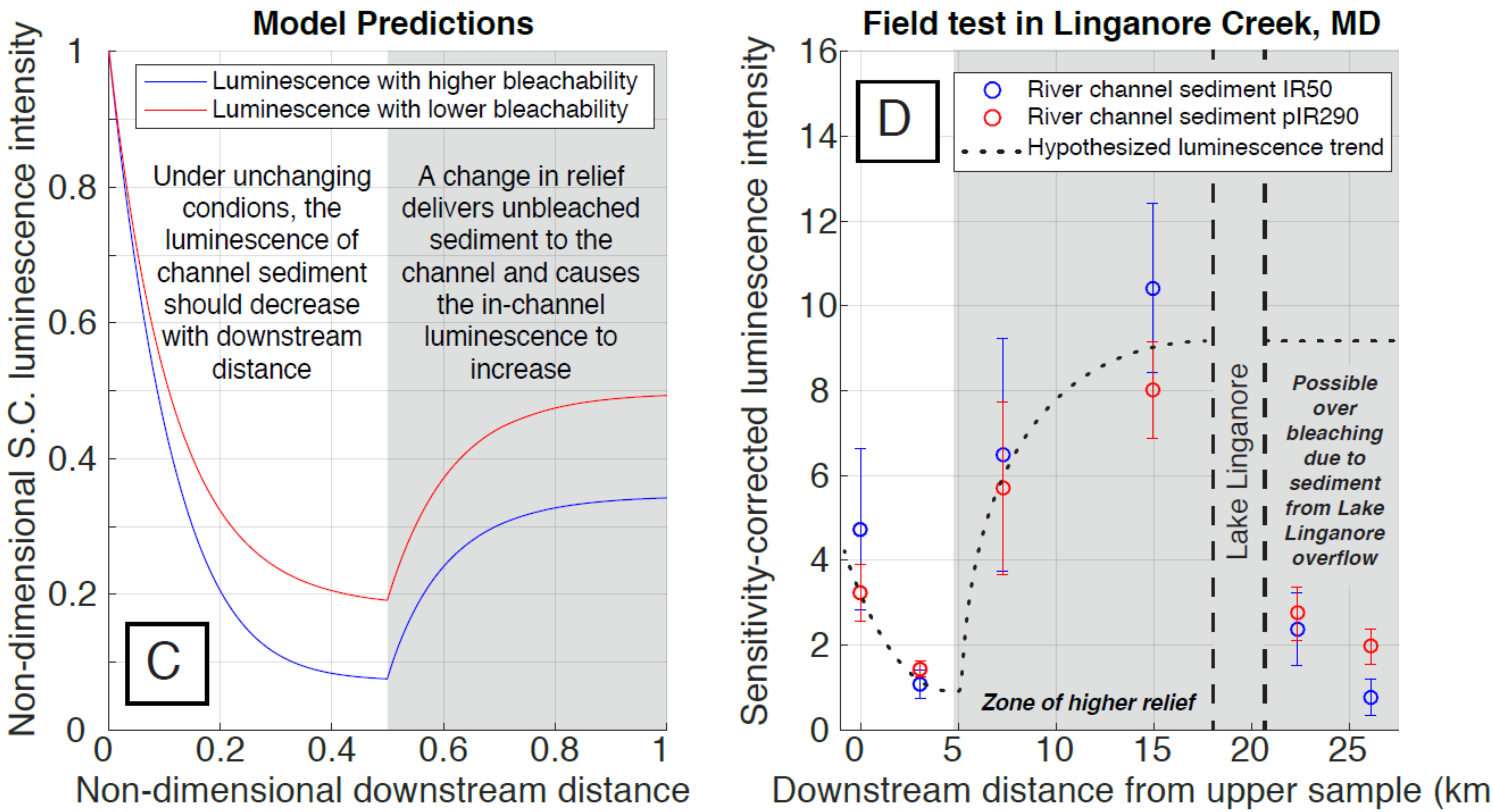
River	Reach length / catchment area	Method		$\bar{U}$	η	ℓ_s
South River, VA	60 km / 550 km^2	*Independently-obtained values*		1.2 (0.12 - 3.0) m/yr	4.4 (1.7-43) % per km	10 (1-25) km
		Luminescence-obtained values	*IR50*	2.8 ± 0.1 m/yr	4.3 ± 1.0 % per km	23 ± 1 km
			pIR290	1.8 ± 0.1 m/yr	6.5 ± 0.2 % per km	15 ± 1 km

Variable definitions: $\bar{U}$ (fine sand time-averaged velocity); η (rate of sediment exchange between channel and storage); ℓ_s (characteristic lengthscale of fine sand transport)

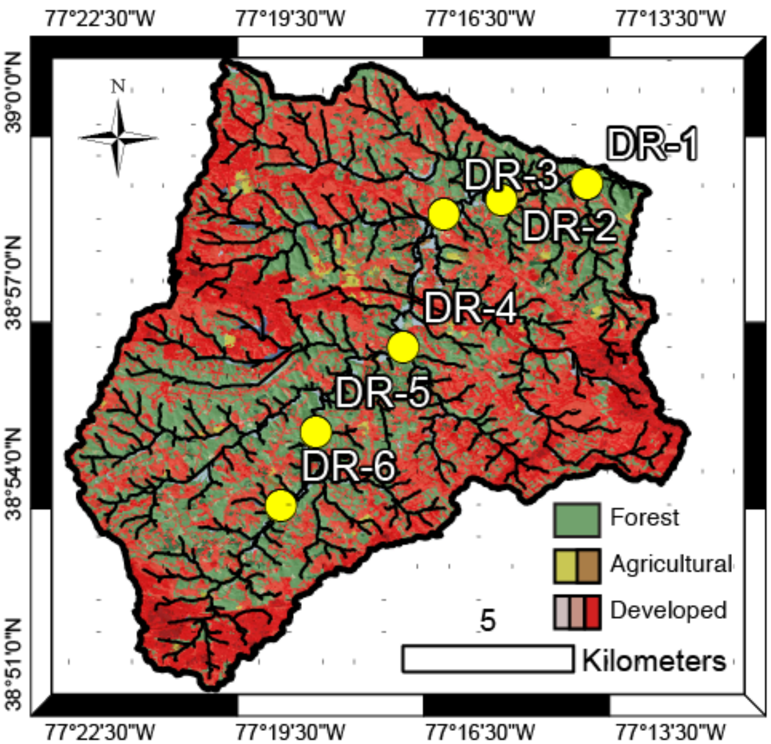

Model Predictions
Luminescence with higher bleachability
Luminescence with lower bleachability
Under unchanging condions, the luminescence of channel sediment should decrease with downstream distance
A change in relief delivers unbleached sediment to the channel and causes the in-channel luminescence to increase
C
Non-dimensional S.C. luminescence intensity
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0.8
1
Non-dimensional downstream distance

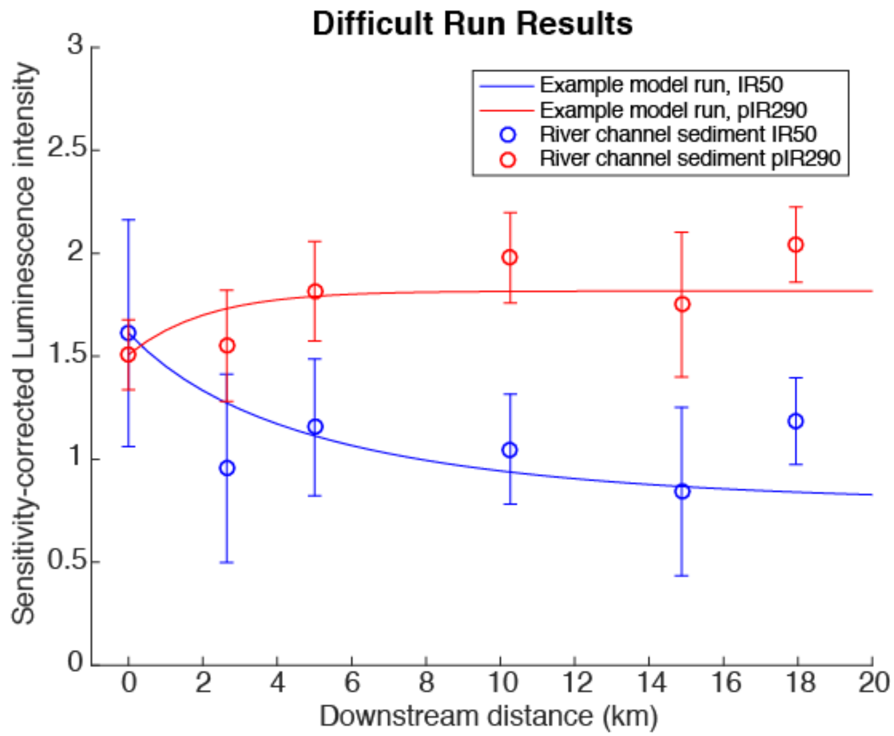


77°21'0"W
77°18'0"W
77°15'0"W
77°12'0"W
77°9'0"W
77°6'0"W
77°3'0"W
39°31'0"N
39°29'0"N
39°27'0"N
39°25'0"N
39°23'0"N
A
Land Cover
Forest
Agricultural
Developed
Middle Agricultural Domain
Lower Forested Domain
Upper Forested Domain
L-1
L-3
L-4
L-5
L-6
L-7
N
5
Kilometers
B
Valley Cross-sectional Relief (meters)
Lake Linganore (removed)
Forested higher relief reach
Agricultural lower relief reach
Forested higher relief reaches
15
25
35
45
55
65
75
0
5000
10000
15000
20000
25000
30000
35000
Distance Upstream of the Monocacy River, MD (meters)



Model Predictions
Luminescence with higher bleachability
Luminescence with lower bleachability
Under unchanging condions, the luminescence of channel sediment should decrease with downstream distance
A change in relief delivers unbleached sediment to the channel and causes the in-channel luminescence to increase
C
Non-dimensional S.C. luminescence intensity
Non-dimensional downstream distance
0
0.2
0.4
0.6
0.8
1
Field test in Linganore Creek, MD
D
River channel sediment IR50
River channel sediment pIR290
Hypothesized luminescence trend
Lake Linganore
Possible over bleaching due to sediment from Lake Linganore overflow
Zone of higher relief
Sensitivity-corrected luminescence intensity
Downstream distance from upper sample (km)
0
2
4
6
8
10
12
14
16
5
15
20
25


77°22'30"W
77°19'30"W
77°16'30"W
77°13'30"W
39°0'0"N
38°57'0"N
38°54'0"N
38°51'0"N
N
DR-1
DR-2
DR-3
DR-4
DR-5
DR-6
Forest
Agricultural
Developed
5
Kilometers


Difficult Run Results
Example model run, IR50
Example model run, pIR290
River channel sediment IR50
River channel sediment pIR290
Sensitivity-corrected Luminescence intensity
Downstream distance (km)
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10
12
14
16
18
20

Conclusions

- We find that luminescence appears to have potential to measure sediment transport rates.
- In some places, the model cannot be applied due to the breakdown of model assumptions
- Futher research and model application will help determine how applicable the model is.

Thank you!!!