Anthropogenic Effects on Global Riverine Sediment and Water Discharge:
The Curious Case of the Mississippi Basin

CSDMS COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

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Introduction

- Understanding riverine sediment dynamics is an important undertaking for both **socially**-relevant issues such as agriculture, water security and infrastructure management and for our **scientific** analysis of landscapes, river ecology, oceanography and other disciplines.
- Ever increasing human activity during the **Anthropocene** have affected sediment dynamics in two major ways: (1) an increase in hillslope erosion due to agriculture, deforestation and landscape engineering and (2) trapping of sediment behind dams and other man-made reservoirs.
- The intensity and dynamics between these man-made factors vary widely across the globe and in time and are therefore hard to predict.
- Here we use a distributed global riverine sediment and water discharge model (*WBMsed*) to compare a **pristine** (no human impact) and **disturbed** (including human impact) simulations, to provide a **quantitative description of human impact on riverine sediment and water discharge**.

Methodology

WBMsed is a spatially and temporally explicit global riverine model (Fig. 1; Cohen et al., 2013) based on the *WBMplus* (Wisser et al., 2010) water balance and transport model (part of the *FrAMES* biogeochemical modeling framework). Suspended sediment flux (SSF) predictions are based on the *BQART* equation (Syvitski and Milliman, 2007):

$$\overline{Q}_s = wB\overline{Q}^{0.31}A^{0.5}R\overline{T}$$

where

w – **0.02** [-]

$\overline{Q}_s$ – long-term **Average Suspended Sediment** load [kg/s]

$\overline{Q}$ – long-term **Average Discharge** [m^3/s]

A – contributing **Area** [km^2]

R – maximum **Relief** [km]

$\overline{T}$ – long-term average **Temperature** [^{0}C]

$$B = IL(1-T_E)E_h$$

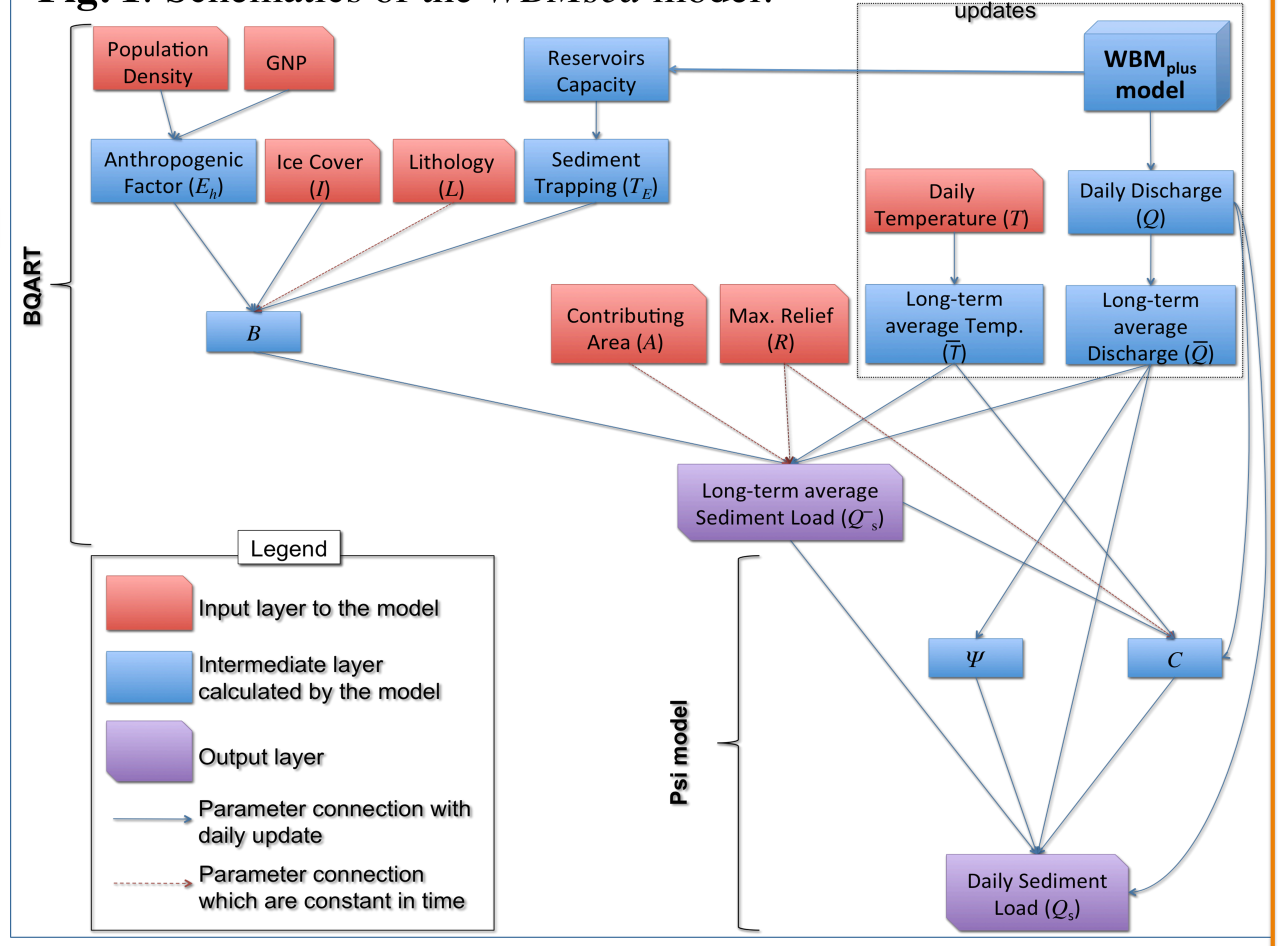
$I = 1+0.09Ag$ (Ag is percentage of **Ice Cover**)

L – **Lithology** Factor

TE – **Sediment Trapping** by reservoirs

E_h – **Anthropogenic** Factor: *f*(**Pop. density, GNP**)

Fig. 1: Schematics of the *WBMsed* model.



Daily suspended Sediment load (Q_s) is predicted with the *Psi* model (Morehead et al., 2003; Fig. 1).

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Anthropogenic effects on SSF and water discharge are investigated by comparing two simulations:

1. **Disturbed** - simulating all human effects on water and sediment discharge as described above;
2. **Pristine** - excluding *irrigation*, *trapping* by dams and reservoirs and the *Eh* Anthropogenic Factor.

SSF and water discharge averaged between 1960-2010 for each simulation are presented in Fig. 2 and 3 respectively. The maps show only river location with a contributing area >40,000 km^2 and average water discharge >30 m^3/s.

Percent difference between these maps (Fig. 2c & 3c) quantify the spatial distribution of **human impact on global rivers**.

Results

Anthropogenic activity resulted in over **25% reduction in riverine suspended sediment flux** (SSF) globally, which is within range of published analysis (Vörösmarty et al., 2003). **Water discharge was reduced by less then 2%**, slightly lower but also within range of published global analyses (Döll et al., 2009; Biemans et al., 2011).

The results show considerable **spatial variability** (Fig. 2 & 3); human activity reduced SSF largely by in-river trapping (e.g. the Aswan Dam on the Nile River; Fig. 2) but are also increased SSF in some locations (e.g. ***The Indian Subcontinent***).

Considerable **intra-basin variability** is observed in some locations (e.g. ***Mississippi Basin***).

Acknowledgment
This research is funded in part by NASA, through the Interdisciplinary Research in Earth Science Program, NNH062DA001N-IDS

References:

Biemans, H., I. Haddeland, P. Kabat, F. Ludwig, R. W. A. Hutjes, J. Heinke, W. von Bloh, and D. Gerten (2011), Impact of reservoirs on river discharge and irrigation water supply during the 20th century, Water Resour. Res., 47, W03509.

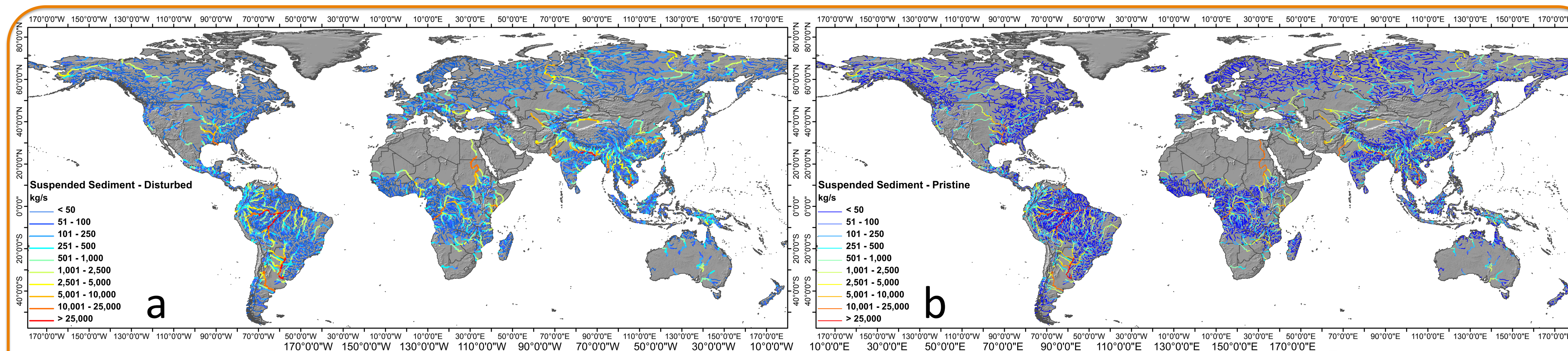
Cohen, S., A. J. Kettner, J.P.M. Syvitski and B.M. Fekete (2013), WBMsed, a distributed global-scale riverine sediment flux model: Model description and validation, Comp. & Geosci 53: 80–93.

Döll P., Fiedler, K., and Zhang J. (2009), Global-scale analysis of river flow alterations due to water withdrawals and reservoirs. Hydrology and Earth System Sciences 13: 2413-2432.

Syvitski, J.P.M., and Milliman, J.D., (2007), Geology, geography, and humans battle for dominance over the delivery of fluvial sediment to the coastal ocean. Journal of Geology, 115(1), 1-19.

Vörösmarty, C.J., Meybeck, M., Fekete, B., Sharma, K., Green, P., Syvitski, J.P.M., (2003),Anthropogenic sediment retention: major global impact from registered river impoundments. Global and Planetary Change 39 (1–2), 169–190.

Wisser, D., Fekete, B.M., Vörösmarty, C.J., Schumann, A.H., (2010), Reconstructing 20th century global hydrography: a contribution to the Global Terrestrial Network- Hydrology (GTN-H). Hydrology and Earth Sys. Sciences 14(1), 1-24.0



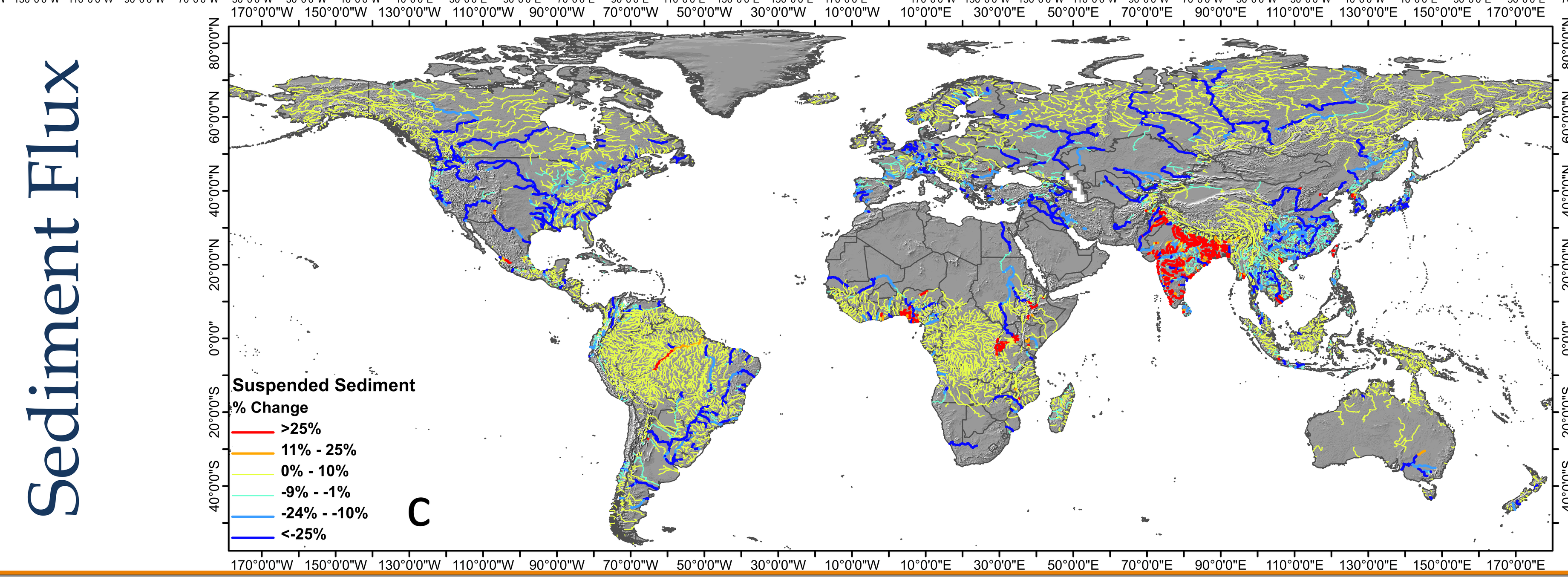


Fig. 2: Mean SSF between 1960-2010 with human effects (**a**), without human effects (**b**) and percent difference between the two simulations (**c**). ***Positive*** values = ***increased*** SSF due to anthropogenic activity.

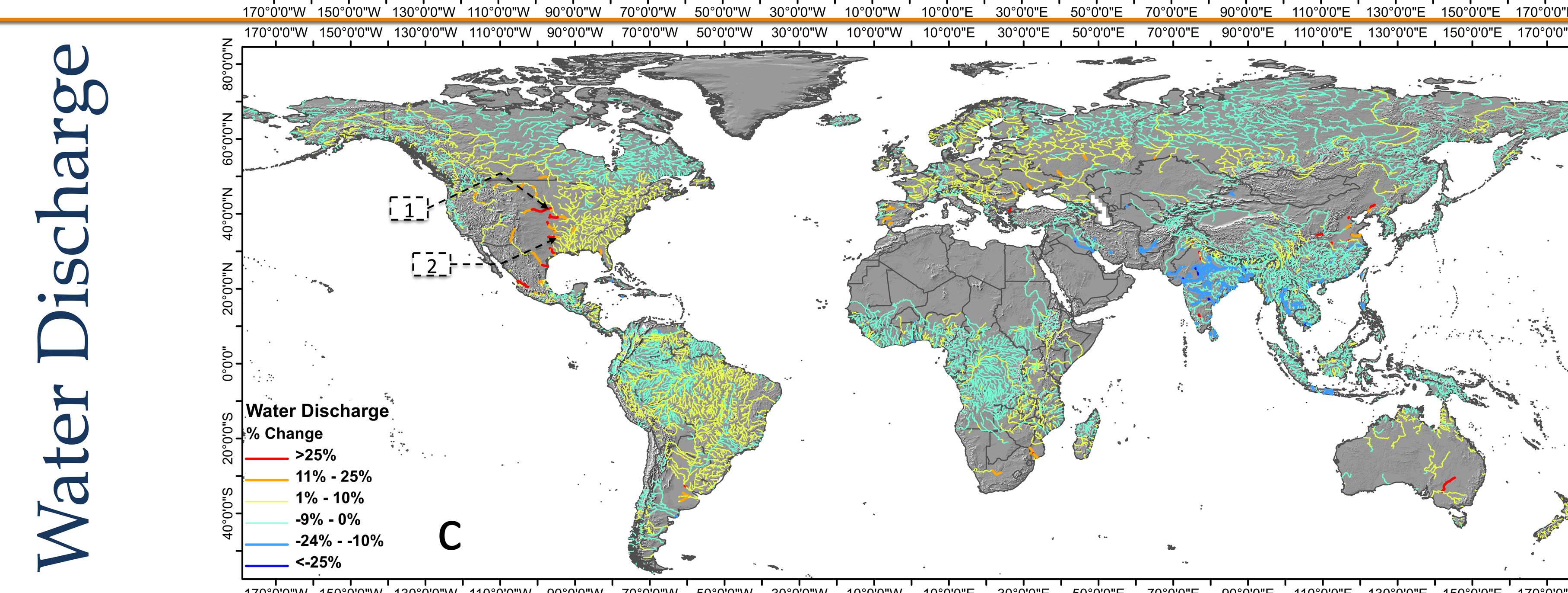
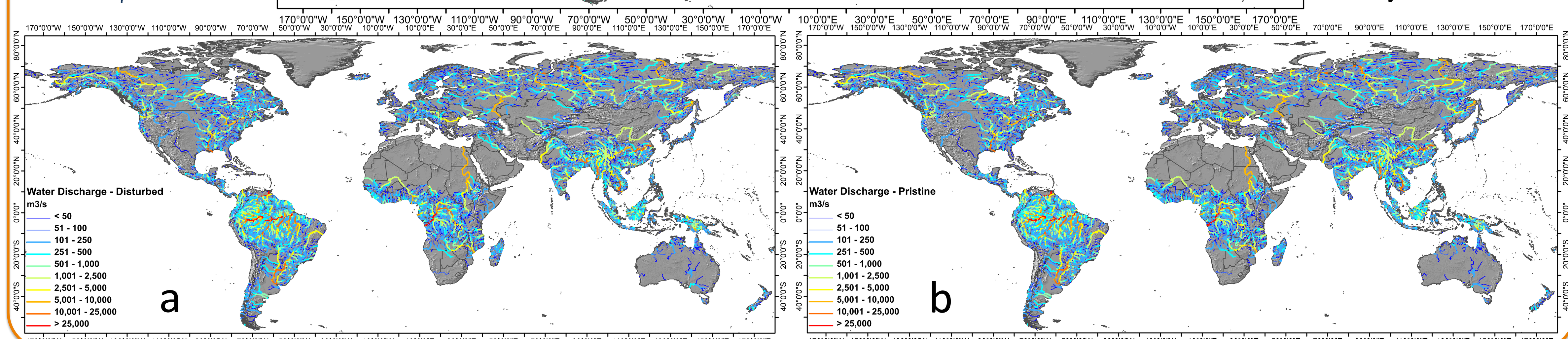


Fig. 3: Mean water discharge between 1960-2010 with human effects (**a**), without human effects (**b**) and percent difference between the two simulations (**c**). ***Positive*** values = ***increased*** discharge due to anthropogenic activity.



The western tributaries of the **Mississippi River** show an *unusual* anthropogenic effect in which sediment flux is reduced while water discharge increases (Fig. 2 & 3).

In our simulations this is due to considerable intake of **groundwater** for irrigation (Ogallala Aquifer) which adds to the surface water balance.

There is anecdotal evidence to support these model predictions; a number of gauging stations have recorded increasing water discharge trends since the mid 20th century in this part of the Mississippi Basin (e.g. Fig. 4) suggesting that increased anthropogenic activity resulted in increasing river discharge. Clearly more research is needed.

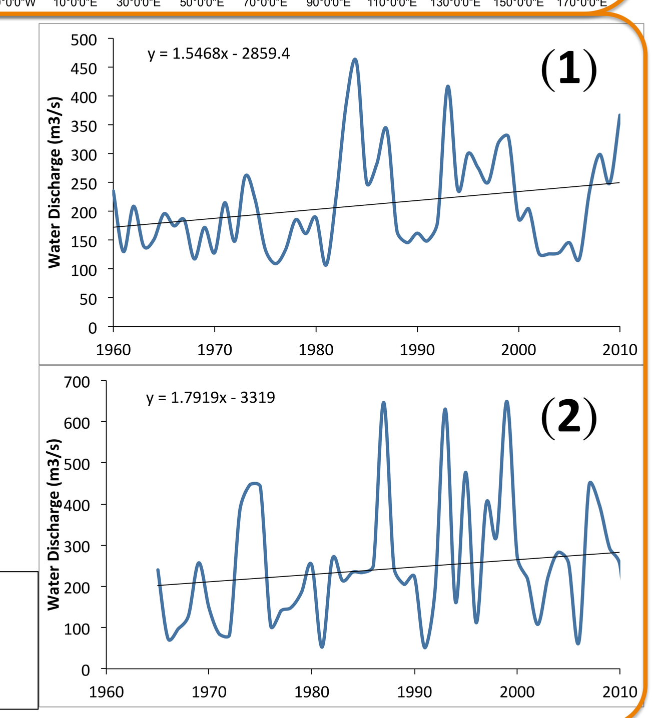


Fig. 4: Water discharge for USGS sites (**1**) Platte River at Louisville, Nebr., and (**2**) Arkansas River at Tulsa, OK. (Fig. 3c)

Conclusions

- Anthropogenic activity increases sediment production by promoting **soil erosion** but also reduce riverine sediment flux by **trapping** sediment upstream of dams in reservoirs.
- Globally the **net affect** is a **considerable reduction in sediment flux** in large rivers. However this complex anthropogenic driver is highly **spatially variable**.
- Human effect on riverine **suspended sediment flux** much exceeds anthropogenic effects on **water discharge.**
- In some locations (e.g. Mississippi Basin) anthropogenic effect on water discharge is opposite to its effect on SSF.