Effect of Water Temperature on Cohesive Streambank Erosion

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AGU American Geophysical Union

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Background

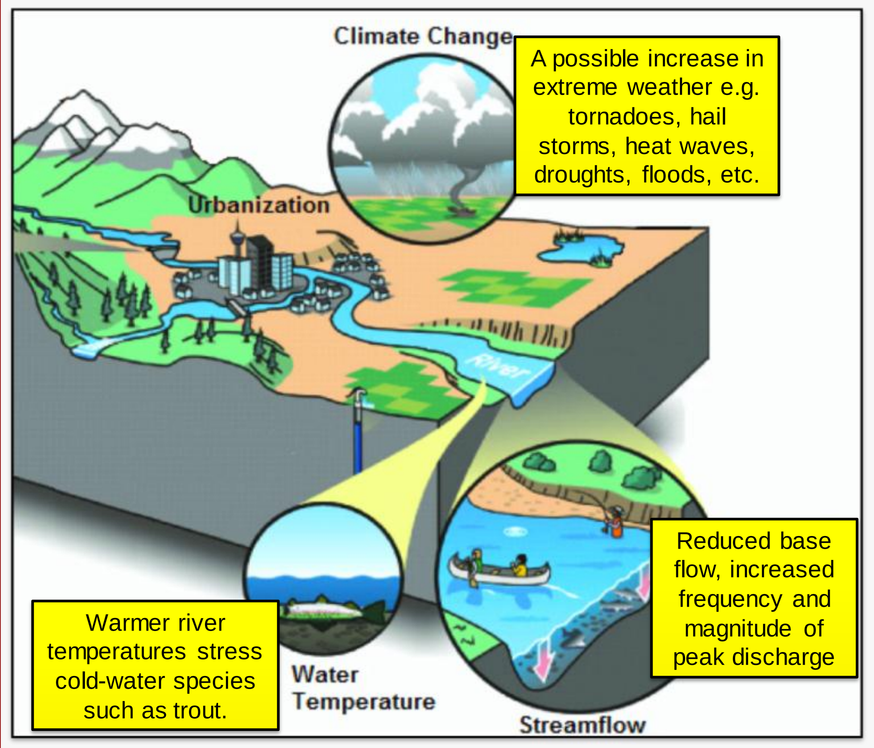

Fig. 1- Climate change and urbanization effect on stream temperature and hydrology
(picture source: The European Water Platform; *www.wsstp.eu*)

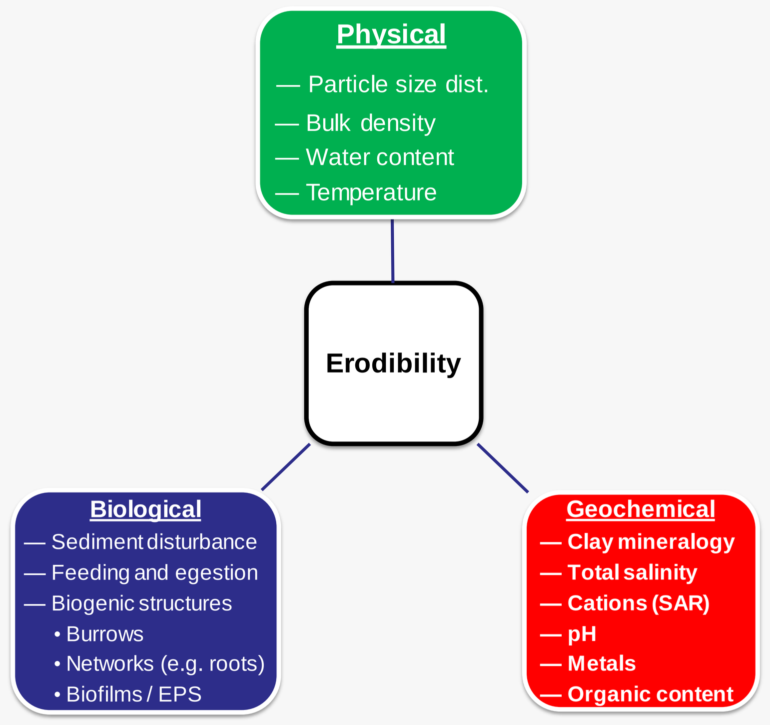

Fig. 2- Soil properties and processes that affect erodibility. They are dynamically linked, and the net impact of any individual property on erodibility for natural soil is dependent on the interactions between properties.

Increasing human populations and global climate change will severely stress our water resources (Fig. 1). One potential unforeseen consequence of these stressors is accelerated stream channel erosion due to increased stream temperature, which affects the surface potential and hence stability of cohesive soils. Summer thunderstorms in urban watersheds can increase stream temperature >7°C and the impact of global warming on average stream temperature is already evident in some stream systems (Nelson and Palmer 2007; Kaushal et al., 2010).

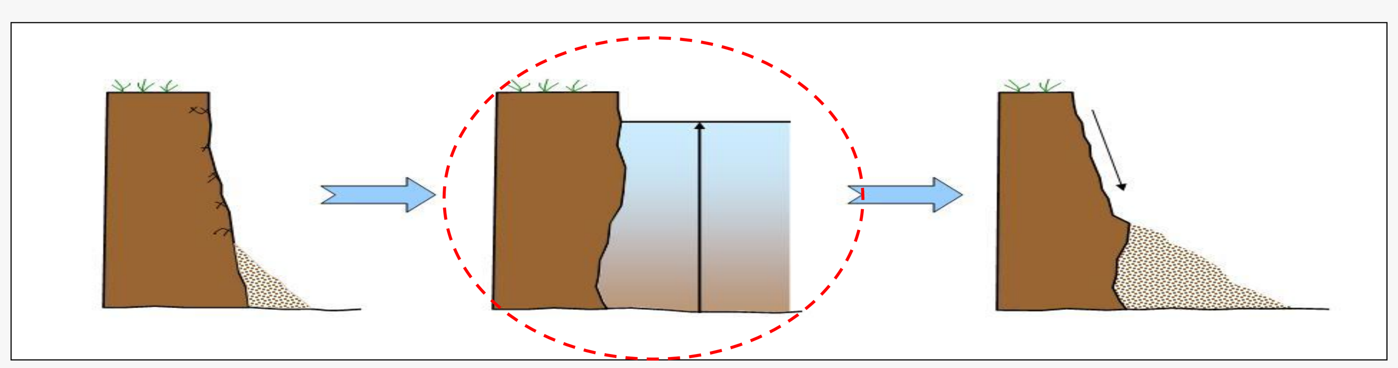

Fig. 3- Streambank retreat is a cyclic process where subaerial processes weaken the soil surface, causing subaerial erosion. During storm events, soil is eroded from the bank toe, leaving an unstable bank. Following a drop in water level, the streambank collapses, depositing additional material at the bank toe. This research focuses on the effect of stream temperature on the second process, fluvial erosion.

Temperature is theorized to be positively correlated with cohesive soil erodibility; however, few studies have directly investigated this process (Fig. 2). Kelly and Gularte (1981) found that erosion rates increased by a factor of 3 for homogeneous illite beds when temperature increased from 10 to 30 °C. Zreik et al. (1998) found that changes in ambient temperatures during a series of flume experiments affected the stability of the surface sediment. At a constant excess shear stress, sediment beds eroded more deeply at 29°C than at 20°C. Initial estimates indicate a 2°C rise in stream temperature could increase fluvial erosion by 30%. (Wynn and Mostaghimi 2006) (Fig. 3).

Two different hypotheses exist to explain the effects of temperature on erodibility:

1. The increase in erodibility with temperature is caused by a weakening of inter-particle bonds (Mehta and Parchure, 2000). This hypothesis is supported by earlier research that demonstrates a decrease in bulk strength of the sediment with an increase in temperature (Zreik et al., 1998).

2. Second, the increase in temperature decreases the viscosity of the pore water, which contributes to higher permeability and increased velocities at the bed surface (Winterwerp and van Kesteren, 2004).

Objectives

Overall goal is to compare erosion rates of various cohesive soils at differing stream temperatures. Specific objectives are to:

1. Determine if water temperature has a significant effect on the erosion rates of clay samples
2. Determine if clay type influences erosion rates, particularly with regards to temperature effects.

Methods

Fig. 4- Recirculating flume, 8 m x 1 m x 0.4 m

Fig. 5- Velocity profiler set-up

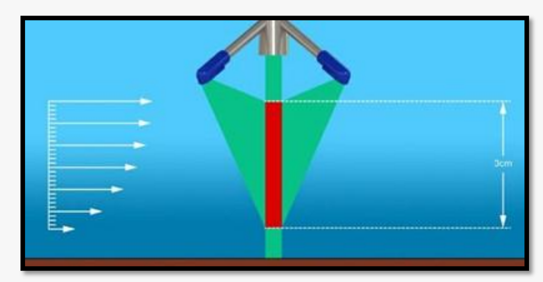

Fig. 6- Velocity profiler sample volume (Vectrino 2004)

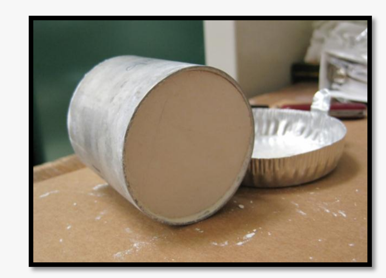

Fig. 7- Kaolinite – sand mixture 5-cm core sample

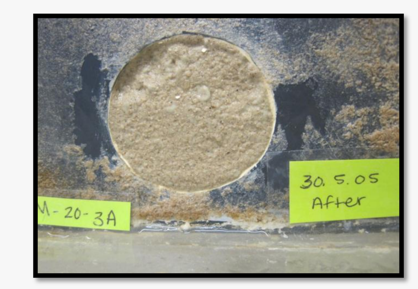

Fig. 8- Erosion of montmorillonite

Tests were conducted in a 8-m x 1-m x 0.4-m recirculating flume (Fig. 4 and 5). An artificial wall was installed to decrease the channel width to 40 cm. A 5-cm core sample was placed in the artificial wall to simulate a streambank. Three different clays, kaolinite, montmorillonite, and vermiculite, were used to capture a wide array of clay characteristics (Fig 7 and 8). The kaolinite and montmorillonite samples were clay-sand mixtures, while the vermiculite was a natural soil. Three water temperatures (12ºC, 20ºC, 27ºC) were analyzed. Erosion rate was measured under 0.1 - 20 Pa range of shear stress. As the clay was eroded, the sample was pushed forward so that the sample remained flush with the wall. Erosion depth and velocity properties were measured continuously using the Nortek AS Vectrino II 3D velocity profiler (Fig. 5 and 6). A Zetasizer 3000HS (Malvern Instruments, Worcestershire, UK) was used to determine the zeta potential for each clay type at water temperatures of 12, 20, and 27˚C (Fig. 12). Statistically significant differences in mean erosion rates with temperature were tested using the bootstrap method.

Summary of Findings

There was a significant difference (α = 0.05) in erosion rates for the kaolinite mixture between 12ºC and 20ºC, and for the vermiculite soil between 20ºC and 27ºC (Fig. 9 and 10). There was a little correlation between shear stress and erosion rate (Fig. 9, 10 and 11).There was no correlation between erosion rate and water temperature for the montmorillonite samples. Montmorillonite erosion was primarily due to mass failure of the sample. It is believed that the high cohesion of the montmorillonite limited surface erosion due to fluvial stresses; however, mass erosion occurred once the structural strength of the sample was surpassed as the sample weight and moisture content increased following wetting (Figure 11 and 13). From these results it is clear that the effect of temperature on erosion rate varied with clay mineralogy (Fig. 14). Mass wasting of montmorillonite would not have been detected if the sample has been placed in the bed of the flume.

Conclusions and Future Work

This research determined fluvial erosion rates of cohesive soils with kaolinite and vermiculite mineralogy significantly increase with increasing stream temperature. Erosion of vermiculite dominated soil samples more than tripled with a 15˚C increase in water temperature. The erosion of kaolinite doubled with a 7 degree increase in water temperature. Results also showed that the effect of water temperature on erosion also varied with clay mineralogy and soil structure. The erosion of montmorillonite was not influenced by temperature; rather, the loss of structural strength of the sample dominated erosion events as indicated by many occurrences of mass erosion during testing. This result suggest that water temperature effects became less significant as inter-particle bond strength increases. Additionally, the mode of montmorillonite erosion demonstrated that the vertical orientation of the sample in this study proved advantageous as the erosion processes (i.e. fluvial versus mechanical) could be discriminated.

Results from this research suggest that stream channel enlargement associated with urbanization may not entirely be due to changes in catchment hydrology, but may also be linked to increases in water temperature. This finding would then imply that urban stormwater management practices should be designed to control for water temperature increases, in addition to stream discharge. Further research will be conducted to confirm this result, and future studies will investigate the effect of pH and salinity on cohesive soil erosion.

Results

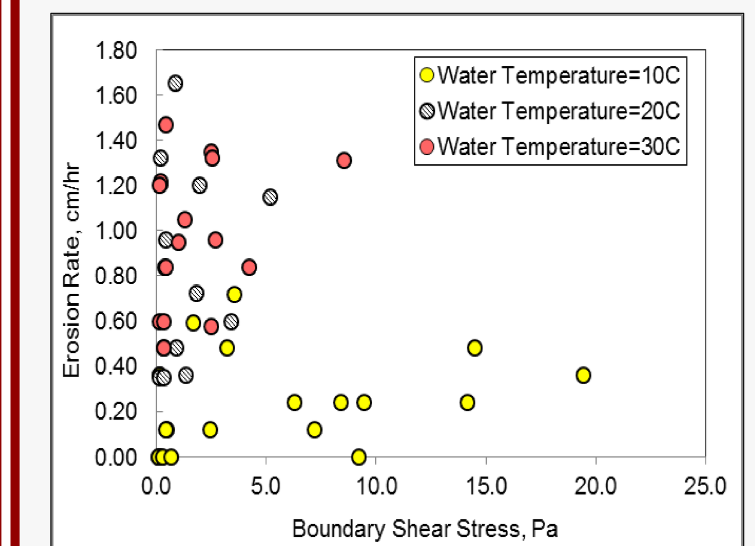

Fig. 9- Erosion rates vs boundary shear stress for Kaolinite

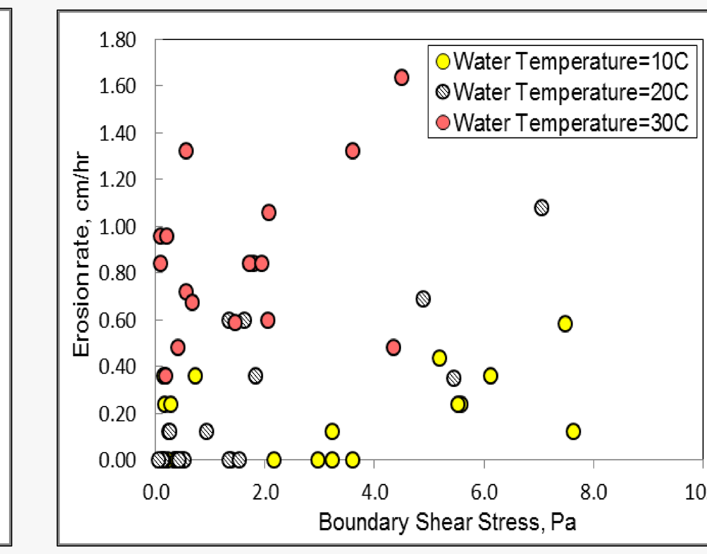

Fig. 10- Erosion rates vs boundary shear stress for Vermiculite

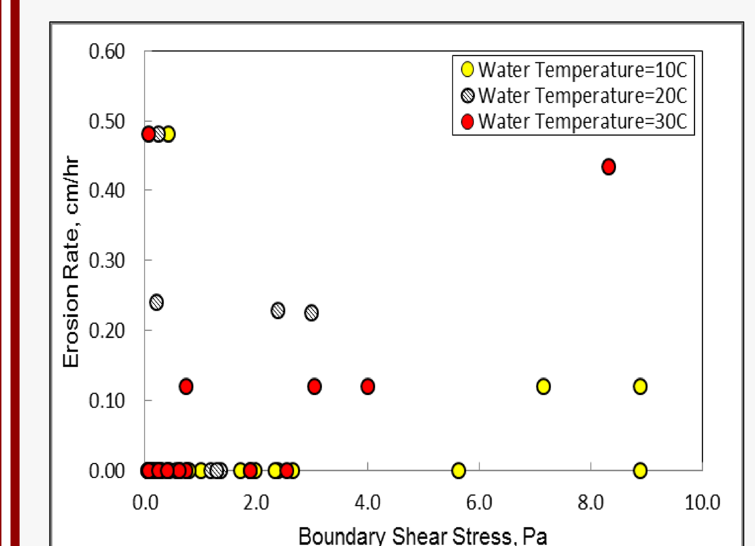

Fig. 11- Erosion rates vs boundary shear stress for Montmorillonite

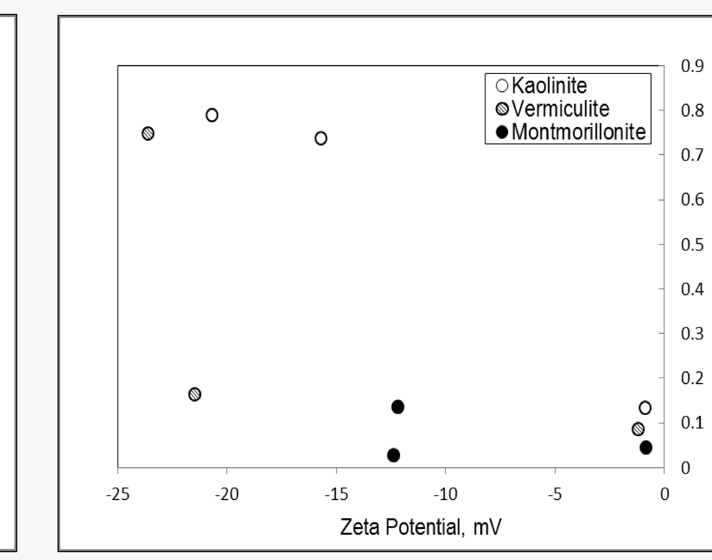

Fig. 12- Er/u* vs zeta potential for different clay minerals, where Er is the erosion rate (cm/hr) and u* is the shear velocity

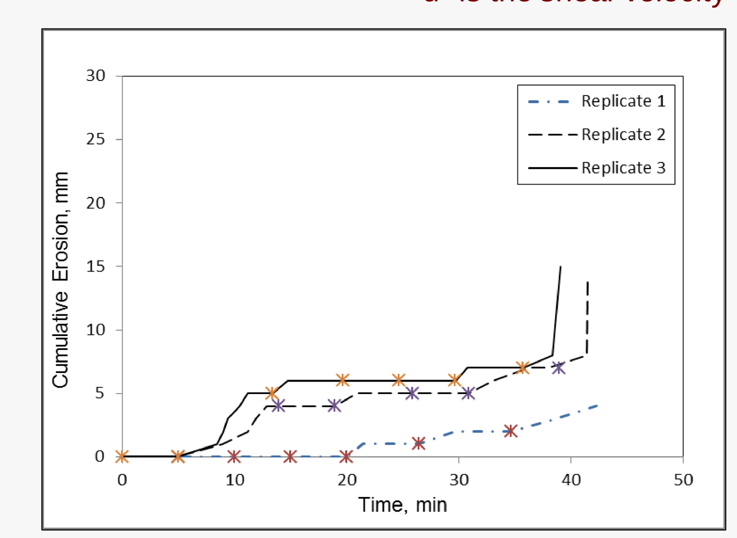

Fig. 13- Cumulative erosion vs. time for montmorillonite replicates at 12˚C; An asterisk indicates a change in flume setting.

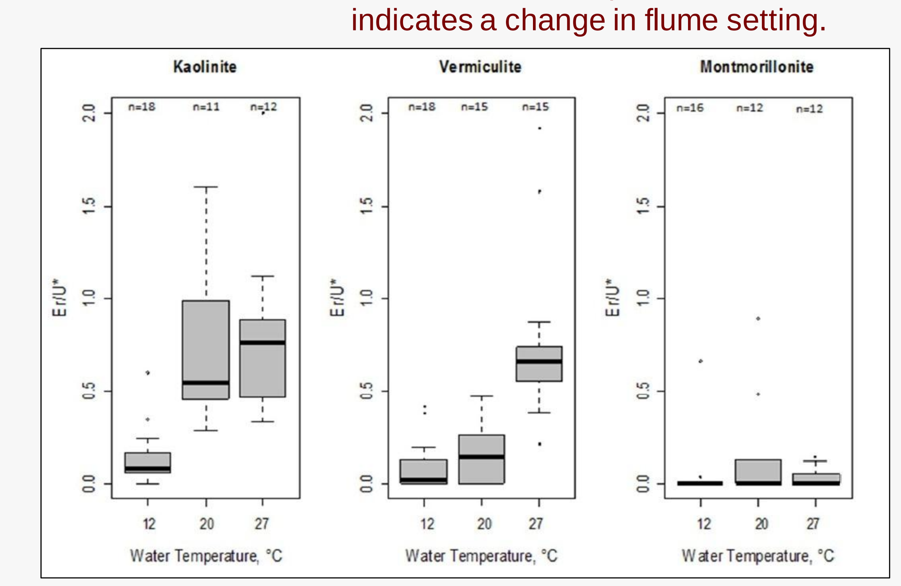

Fig. 14- Distribution of erosion rate divided by shear velocity, Er/u*, at each average water temperature.

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