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Erosion: indication in the water level and flow dynamics

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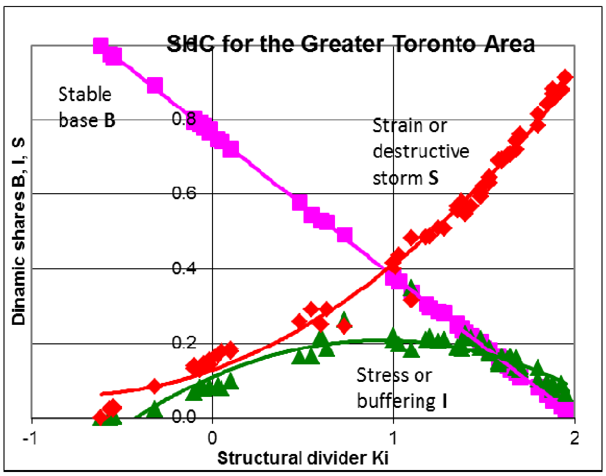
Erosion is a serious issue for the urban infrastructure since development accelerates the erosion of river banks, especially the avalanche type. Precipitation, stream flow, and the tide level are the water related agents of erosion. Due to the spatial and temporal variability of degrees of urbanization and intensity of the agents, the degrees of erosion fluctuate accordingly. The highest degree of erosion within the examined spacetime belongs to the bank slide event happened in August 2005 at one of the gauged catchments (HC027) destroying a busy route of the Toronto city. The objective of this project is to quantify the variability of the bank erosion through river level and flow dynamics of differently urbanized eroding streams of Greater Toronto Area using the original method named Harmonized Frequency Analysis (HFA) (Vedom 2011).

Method: HFA is the hydrological tool to assess the functionality and sustainability of the entire water cycle and each variable in it. Its main principle is the universal Structural Harmony Chart (SHC, fig) representing the scale invariant structure of the water cycle time-space dynamics in relative dimensions.



The three lines in SHC denote: (1) the statistically stable base dynamic component (share) B of all examined variables totalized within the system as the straight line K_i = -2.618*B+2; (2) the universally bounded stress or buffering component I =f(K_i) (the arching line); and (3) unbounded destructive storm component S = f(K_i). The total relative dynamics of each variable is the sum of its three components: B+I+S=1.Thus, the right wing tip of the graph (K_i>1.5, S>0.6) mainly represents the variables with destructive function; the left wing tip (K_i <0, B>0.75) mostly manifests their self-stabilizing functionality; all variables lying in between largely signify the buffering function. The urban flow generally locates on the tip of the right wing (Ki>1.5) and indicates its very destructive nature; its corresponding level always shows more buffering function.

In absolute dimensions, the predominant functionality of each variable is estimated by the power parameters of HFA: PBD, PID and PSD - the power of base, inter and storm dynamics, respectively, which dimensions are the same as original variables have:

$$PBD = dQb*Nb*HEI; PID = dQi*Ni*HEI; PSD = dQs*Ns*HEI,$$

where dQb, dQi and dQs are daily base, inter, and storm dynamic limits of each variable; Nb, Ni, and Ns are the frequencies of their occurrence; HEI is the hydrosphere elasticity index, a specific stress-strain ratio of each variable daily dynamics to the dynamics of temperature, which is a point of reference:

$$HEI_i = (S_i - I_i)*(K_i - K_t)/(B_t - I_t)$$

where S_i, I_i, and K_i are the storm and inter components of a variable and their structural divider, respectively; B_t, I_t, and K_t are the base and inter components of temperature, and the structural divider.

Data: Flow and stream levels of twenty hydrometrical stations were chosen for the analysis between the years of 2004-2009. The stations belong to Toronto and Region, and the Credit Valley Conservation Authorities (TRCA and CVCA). For comparison of the absolute values of the flow power parameters the specific yield of flow is considered, in order to avoid direct influence of a watershed size on discharge.

Result demonstrates a rather intricate set of conclusive parameters, indicating equal involvement of all three components of both level and flow in assessment of the erosion process.

HFA power parameters of level and specific yield dynamics for TRCA locations, 2004-2009

Station	F, km^2	HEI	PBD	PID	PSD	Sum
HC030 yield	204	2.04	0.35	1.70	0.44	2.49
HC030 level		0.57	2.2	6.9	0.34	9.4
HC017 yield	63.2	2.19	0.16	0.78	0.64	1.58
HC017 level		0.89	1.9	6.6	0.75	9.3
HC033 yield	70.6	2.11	0.43	2.09	0.51	3.03
HC033 level		0.96	2.1	7.6	0.50	10.2
HC003 yield	800	1.32	0.14	0.51	0.13	0.78
HC003 level		0.31	1.3	2.9	0.29	4.4
HC009 yield	197	1.34	0.09	0.34	0.11	0.54
HC009 level		0.56	1.1	3.0	0.35	4.5
HC018 yield	106	1.52	0.21	0.82	0.26	1.29
HC018 level		1.26	1.6	6.2	1.88	9.7
HC019 yield	93.5	1.58	0.15	0.56	0.17	0.88
HC019 level		0.48	0.8	2.4	0.56	3.8
HC022 yield	186	0.83	0.31	0.82	0.12	1.25
HC022 level		0.92	1.7	6.8	0.63	9.1
HC024 yield	316	1.39	0.35	1.46	0.45	2.26
HC024 level		0.75	2.2	8.4	0.57	11.2
HC027 yield	58	1.73	0.61	2.56	0.36	3.53
HC027 level		0.67	3.4	10.9	0.52	14.8
HC028 yield	77.7	1.88	0.14	0.71	0.48	1.33
HC028 level		0.81	1.8	5.5	0.69	8.0
HC031 yield	148	2.24	0.10	0.46	0.56	1.12
HC031 level		1.00	1.9	6.7	2.07	10.7
HC032 yield	94.8	1.32	0.07	0.26	0.16	0.49
HC032 level		0.73	1.2	3.3	0.87	5.4
HC049 yield	251	1.54	0.14	0.57	0.22	0.93
HC049 level		0.76	2.1	6.1	0.78	8.9

1. Spatially, the intensity of the in-stream erosion is characterized by simultaneously high values of base and inter power sums (PBD + PID) for both flow and level; the rough numerical threshold of this sum for extreme severity is 2.2*n (m) for level and 0.5*n ($L*s^{-1}*km^{-2}$) for specific yield (n – number of years); remarkably, the storm component does not play any noticeable role in spatial variability, (see the Table);
2. Temporally, there is a highest storm dynamic limit (dQs) for entire period at the very date of the event, while the PBD+PID sum is the lowest for the year where the bank-slide event happened in the year 2005 at the location (HC027).
3. Years analyzed separately do not lead to any certain conclusions neither for low nor for high water agents: in order to receive any certain results, daily long-term time series of flow and level have to be processed in whole.

Obtained results for the dominant role of the base and inter components of a stream flow and level in erosion process are supported in literature. Karmaker and Dutts (2013) have found that seepage, which is the most pronounced during the low-flow periods, has a dominant effect in developing undercuts leading to bank sliding. Conventionally the water level is associated exclusively in estuarine areas of the coastal and bank erosion (Environment Canada 2010); however, based on current investigation the water level also has significantly strong effect in fluvial systems.

References:

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