Dissolved Silica in Boreal Catchments

Zi H. Lin
Watershed Ecosystems Graduate Program, Trent University，Peterborough, Ontario, Canada
zilin@trentu.ca

Peter J. Dillon
Department of Chemistry, Trent University, Peterborough, Ontario, Canada

Summary

We analyzed long-term Si concentrations and fluxes in 20 catchments located in the southern Boreal ecozone in Ontario, Canada to determine if there were any trends related to the declines of acid deposition, climate change and/or forest harvesting. We also compared the silicon flux with other measures related to mineral weathering rates including base cations (Ca, Mg, Na and K) and aluminum (Al) fluxes. These results are discussed in terms of the mineralogy of the catchments.

Introduction

Dissolved silica (DSi) is one of the most important chemical components in natural waters. It can be a limiting nutrient for phytoplankton growth and biomass, particularly where there is phosphorus (P) and nitrogen (N) enrichment. The availability of dissolved silica in natural water can also regulate the species composition of phytoplankton assemblages. The amount of dissolved silica in natural water usually depends on both abiotic factors and biotic factors. Abiotic factors include mineral composition of the bedrock and soil, weathering rate, and hydrology (flow rate and flow path). Biotic factors include biological activity in terrestrial systems as well as in streams and wetlands.

Method

The data were collected from 20 catchments in central Ontario in Haliburton County or the District of Muskoka during the 20-yr period from 1976 to 2007. The catchments are situated near the southern boundary of the Pre-cambrian Shield; all are in granitic terrain. All streams are headwater streams, although several of the catchments include small beaver ponds or Sphagnum-conifer swamps in the drainage. The vegetation at many of the sites is dominated by mature hardwood forest (maple and beech) with occasional pine species. The bedrock is dominated by granitized hornblende and biotite gneisses, amphibolites and schists, and minor amounts of diorite (Law, 1991).

Streams draining each of the 20 catchments have been monitored for stream flow continuously and chemistry on a weekly to bi-weekly basis. These data have been analyzed to determine the long term trends in runoff and in Si flux and Si concentration for each stream. The coherence or synchronicity between the measurements made in these streams has been assessed. Based on the geological and physiographic information about this region, we compared and attempted to explain the differences and similarities in these patterns. Finally, a multivariate regression model was developed for these catchments to predict the silica flux based on the mass percentage of amphibolite and schist (AS), peat (PEAT), sand (SAND) and outwash (WASH), stream density (ASTRML) (defined as ratio of area to stream length).

Results

Long-Term Trends or Patterns

The annual average silica concentration patterns in 6 sub-catchments in the Harp Lake watershed, when standardized as Z-scores, were very similar (Fig. 1). There was more variability between sites from 1976 to 1983, but between 1984 and 1998, the patterns at these sites were very coherent.

These two graphs clearly demonstrated that the annual DSi flux from each catchment is largely driven by areal runoff, which is a function of precipitation and evapotranspiration. Before 1985-86, the Z-Score graphs show that the annual flux was almost always above the long-term average level while the annual concentration was almost always below the average level. After this period, the annual concentration increased and stayed above the average level until 1992, at which time it decreased again. In contrast, the annual flux varied significantly after 1992.

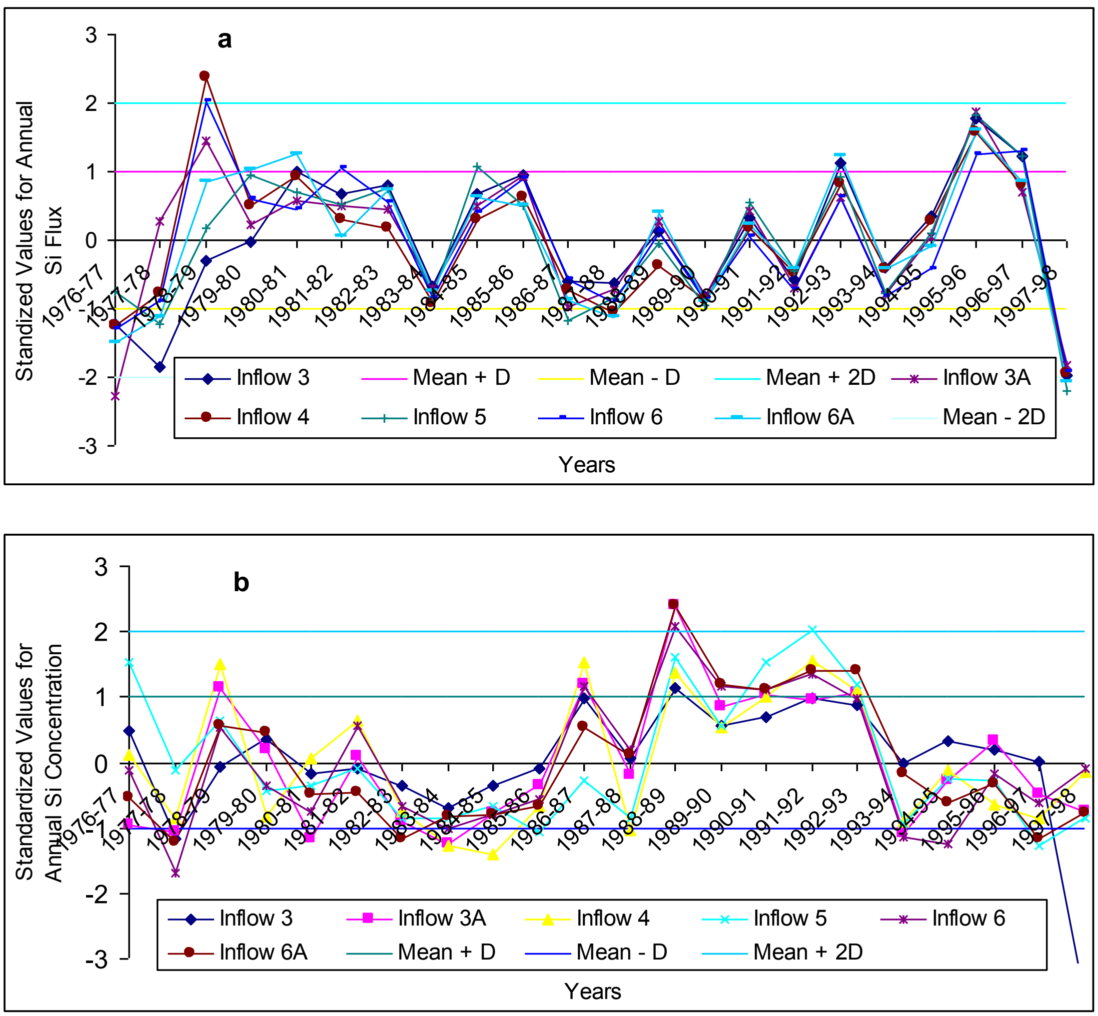

Fig 1. Flux (a) and Flux-Weighted Concentration (b) of Si in Harp Lake.

Regression Analysis

Multiple regression analysis yielded the following equations to estimate Si flux and volume-weighted Si concentration:

Si Flux

Si Flux (mg/m^2) = 77.7 SAND – 620 WASH + 1.01×10^5 (1/ASTRML) – 12.2 PEAT + 1210

$r = 0.82$, $R^2 = 0.67$, $R^2_{Adjusted} = 0.58$, MSE = 3.97×10^4, F = 7.43, P<0.002

Si Concentration (Flux/Runoff)

Si Concentration (ug/L) = - 75.2 POND + 126 SAND - 1.30×10^3 WASH - 0.22 ASTRML -6.00 AS - 52.5 PEAT + 3280

$r = 0.91$, $R^2 = 0.83$, $R^2_{Adjusted} = 0.75$, MSE = 7.10×10^4, F = 10.2, P<0.0001

The empirical equations for both volume-weighted Si concentration and Si flux have high correlation coefficients ($r = 0.91$, $R^2_{Adjusted} = 0.75$ for Si concentration; $r = 0.82$, $R^2_{Adjusted} = 0.58$ for Si flux).

Based on these results, the proportion of sand, outwash and peat are the most important factors determining Si levels in these streams. The main composition of the sand is silica. Due to relatively high mobility, these sands easily move along the river bed. Outwash, which is the material, chiefly sand or gravel, deposited by meltwater streams in front of a glacier, is also important. PEAT is a measure of the importance of wetlands in the catchment and has a negative coefficient suggesting that the wetlands are a Si sink, reducing Si levels downstream. The same is true of POND; this is a measure of the extent of beaver ponds in the catchment which are also likely effective at trapping silica. ASTRML, (stream density, defined as ratio of area to stream length), is negatively related to the Si flux and concentration, indicating that the higher the stream density, the lower the silica will be.

Conclusions

- There is no long-term change in Si flux in 17 of 20 watersheds, but there was a significant change upward in Si concentration in 7 watersheds.
- All of the inflows have the same long-term flux and runoff patterns, respectively.
- Runoff is a big factor governing the year-to-year changes in flux of silica in catchments.
- Si flux and concentration models showed strong relationships with several surficial geology parameters.

Acknowledgements

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