

Surface Water Chemistry In Glacier Bay Ecosystems

By Robert Stottlemeyer

Long-term, ecosystem-level monitoring and research provide earlier indications of environmental change and considerably improved estimates of impact magnitude. This conceptual approach is widely applied in assessing the effects of atmospheric contaminants and change in land use on terrestrial and aquatic environments. By definition, an ecosystem must have a boundary be it a terrarium or the Mississippi River basin. For research, small (<200 ha) watershed ecosystems have proven quite adequate. The goal is understanding ecosystem structure (components) and functioning (processes). The study of processes focuses on the transfer of nutrients and energy among ecosystem components.

Watersheds in a number of national parks are now used to assess impact associated with atmospheric contaminants. A major concern is the leaching of critical nutrients from ecosystems by atmospheric contaminants such as hydrogen and sulfate in acid rain. Nutrient losses often show up in streamwater draining

the watershed. Long-term change in surface water chemistry has proven effective in detecting early ecosystem response to atmospheric contaminants, change in land use (Bormann and Likens 1979), and fire (Tiedemann et al. 1978). Watersheds are an ideal tool with which to assess factors responsible for natural change prior to human-induced impact (Waring and Schlesinger 1985). But such study must be conducted over the long-term for there are numerous sources of cyclic natural variation in ecosystem processes and chemistry which must be quantified before human-induced impact can be assessed.

In 1984, I and a graduate student, Jane LeTarte from Michigan Tech, began to characterize surface water chemistry and to quantify some of the natural factors responsible for its variation in the national parks of Alaska. The initial study, now completed, was at Glacier Bay National Park and Preserve. Similar study has just been completed at Lake Clark, and is underway at Denali NP and P. Support is provided

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Glacier Bay provided both a logistical challenge and unique opportunity for this type of study. During the last 250 years a major retreat of the glaciers up the bay has exposed entire watersheds after 3700 years (Fig. 1). The result is a gradient of watershed "ages" from recently re-exposed to those deglaciated for 200 years or more. Within 25 years following deglaciation, young watersheds such as Wolf Creek (Fig. 2) began to revegetate with nitrogen fixers as *Dryas* (rose family) and alder (birch family). Nitrogen is an especially limiting nutrient for early revegetation (primary succession), and invading plants with the capacity to fix atmospheric nitrogen for use in protein synthesis have a real advantage. Later successional watersheds, deglaciated for longer periods, are subsequently vegetated with poplar, then spruce, which follows deglaciation by about 120 years. Ecosystem succession is thought to be a major factor causing variation in surface water chemistry. Thus, we had an ideal opportunity to study its effects over a spectrum of successional stages. And we had the chance to look at ecosystems undergoing change during primary succession, a process rarely studied except following volcanism.

We studied five watersheds varying from 30 to >300 years since deglaciation. The oldest was at Trap Bay, a USFS experimental area, south of Glacier Bay, where deglaciation occurred first. The most recently deglaciated was Wolf Creek (Fig. 2). In each watershed we sampled precipitation (about 200 cm/year) chemistry to determine if its quality might influence stream chemistry. Going up Glacier Bay and especially into Muir Inlet one sees a decreasing marine influence on precipitation chemistry. Sodium, magnesium and chloride, primarily of marine origin, decreased rapidly while calcium and potassium, indicative of the relative increase in land mass, increased. Sulfate, a potential atmospheric contaminant, would normally also decrease in concentration with increasing distance from its marine source. But at Glacier Bay the highest sulfate concentration was found at stations well up Muir Inlet. This suggests a local geologic source or the possibility of human-induced atmospheric contamination beneath the prevailing air inversions in this fjord.

The watersheds in earliest successional stages, Wolf and Nunatak, had the highest streamwater discharge per unit area. This reflected their proximity to active glaciers, low evaporation due to low temperatures, and less vegetation for water uptake. The amount of streamwater discharge usually affects its chemical concentration, and this source of natural variation requires long-term study to quantify. In many watersheds there are clear mathematical relationships between chemical concentration and streamwater discharge, which provide an excellent tool for looking at trends in chemical nutrient concentration. But in Alaska there are many glacially-fed drainages and annual and seasonal variation is especially large, and we did not find these relationships at Glacier Bay.

Another tool for detecting trends is watershed chemical budgets determined by measuring precipitation input and streamwater discharge of chemical species. In any solution there must be chemical equilibrium; that is, the positive-charged ions as calcium or hydrogen must be balanced by negative-charged ions such as sulfate or nitrate. With this principle we can determine if atmospheric inputs are retained in an ecosystem, or if atmospheric contaminants may be leaching critical nutrient ions as potas-

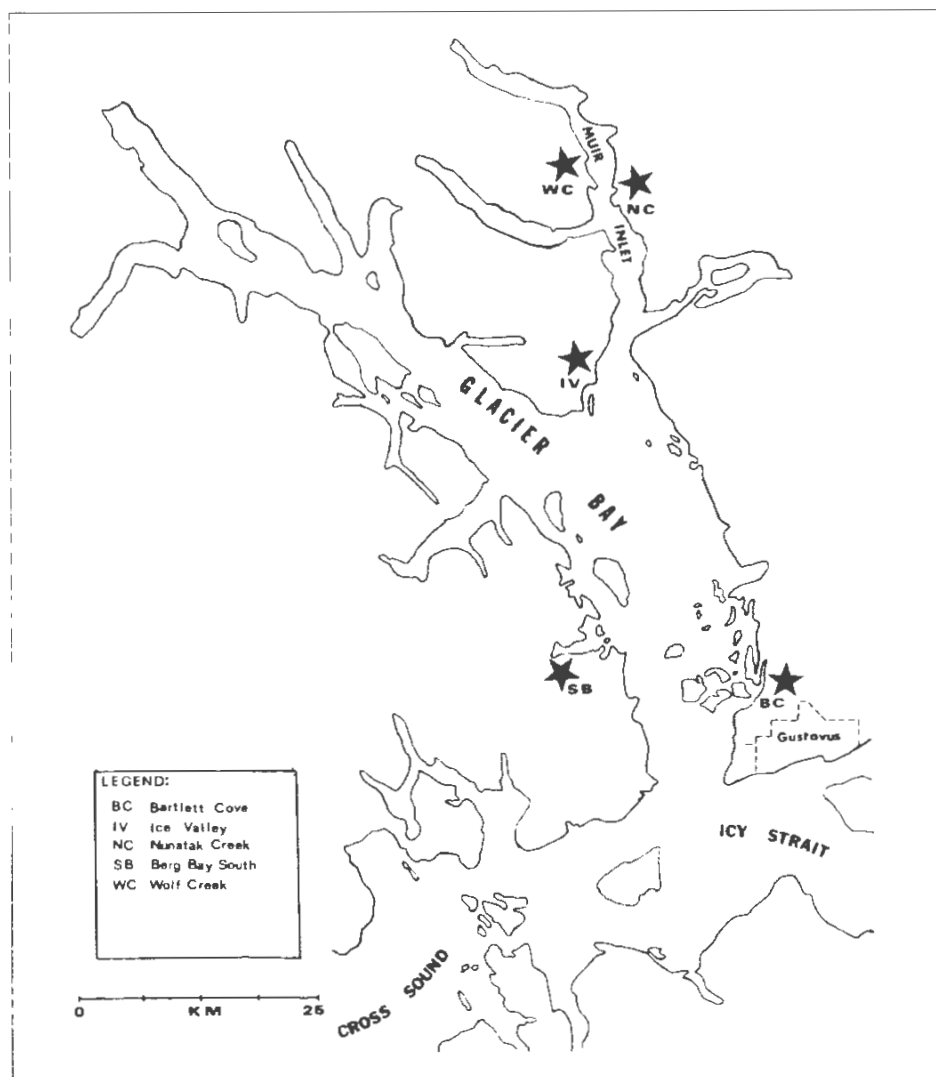


Figure 1. Glacier Bay and Muir Inlet showing approximate locations of the major sampling stations.



Figure 2. Wolf Creek, a young watershed recently deglaciated.

sium from an ecosystem. While our data base at Glacier Bay is too short (three years) to determine very accurate budgets, this principle of chemical equilibrium was applicable to other work there.

The successional stage of the watershed did have an effect on surface water chemistry. Even accounting for differences in bedrock, the loss of calcium was higher from the more advanced successional watersheds. This is likely due to the greater degree of natural acidification by organic matter in such systems. The losses of sodium, magnesium and chloride coincided more with marine atmospheric inputs. Since none of these chemical species is generally limiting nutrients, this is an expected result. Potassium losses were higher in earlier successional watersheds, which likely reflected bedrock quality, potassium's high mobility, and reduced vegetation uptake.

The trend in streamwater nitrogen losses, as ammonium, nitrate, and organic nitrogen, were the most interesting. All were much higher in Wolf Creek. We were especially interested in nitrate since it is a common, and increasing, atmospheric contaminant in many portions of the world. Also, it is a limiting nutrient in most terrestrial ecosystems. Bedrock quality does not affect nitrogen since it must come from atmospheric inputs and/or be fixed by biological processes within the watershed. Our precipitation chemistry showed only trace levels of nitrate or ammonium so we knew any found within the watersheds had to be of biological origin.

In order to better explain why there were such differences in stream chemistry, we focused on the effect of primary succession, particularly that of invading nitrogen-fixing vegetation, on soil and soil water chemistry. Within 30 years following deglaciation, soil pH decreased from 7.4 to 6.3 due just to unaltered precipitation inputs (Fig. 3). After 50 years, which included 20 years of revegetation by alder, the surface soil pH decreased to 4.71. This is a >500x increase in soil acidity in 55 years – all due to natural processes. With the invasion of alder, soil organic matter (shown as carbon in Fig. 3) increased. Organic matter, along with clays, is a major factor increasing soil retention of critically needed ions. This retention ability, or "ca-

tion exchange capacity," reflects the rapidly increasing capacity of these soils to retain calcium, magnesium, potassium, and ammonium. But the rapid gain in hydrogen, as measured by a decrease in pH, displaced some base ions from these retention sites, and the "base saturation" was decreased.

In examining similar data from soils in our watershed deglaciated >300 years ago, these soil properties had not greatly changed from those observed at 175 years. Thus, the greatest change in a number of ecosystem indicators often used to assess human impact, as from acid rain, show considerable natural variation during primary succession. It would be difficult to separate soil change due to acid rain during this time. And in late successional stages, it would also be difficult because of the huge hydrogen pool built up by natural processes in soil. One would need long-term, accurate data to separate the source of trends.

What was the main cause of soil acidification with alder? Nitrogen fixing! In the nitrogen cycle atmospheric nitrogen and hydrogen are symbiotically combined near plant roots and transformed to ammonia, which can be altered to nitrate or organic nitrogen. Alder fixed far more nitrogen than it could biologically utilize. With no other plants to use the excess nitrate, as would be present in later successional stages, there was excess in the soil water. As previously mentioned, chemical equilibrium must be maintained in solutions. We found that all the base or positively-charged ions, as calcium and potassium, in soil water beneath the plant roots were balanced by the negatively-charged nitrate concentration. So nitrate accounted for leaching base cations from the soil leaving hydrogen to acidify it. Ironically, the ecosystem's most rapid acidification resulted from its loss of nitrate, a critically limiting and strongly conserved nutrient in later ecosystem successional stages.

Most ecosystems have undergone such pronounced change at one time or another. We must first understand such ecosystem processes before we can be certain we are maintaining them, and this step is a prerequisite to preserving biological diversity. Much effort has gone into assessing various research tools

by which we may monitor ecosystem functions. But there is considerable need to more fully quantify the sources and magnitude of natural variation for these tools to be more effective. From such study we will gain much needed new insight into ecosystem processes.

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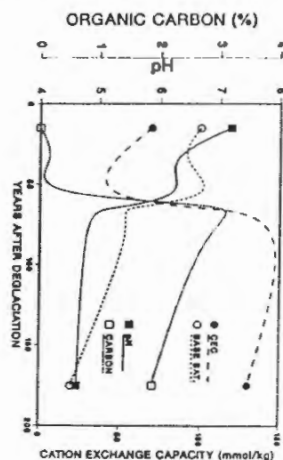


Figure 3. Base Saturation (%).



Interpretation of natural resource management practices at Cuyahoga Valley NRA is the subject of an article by Supervisory Park Ranger Carol Spears, to be published in a spring 1988 issue of the NPS Courier. Here, visitors participate in a park tagging program by capturing monarch butterflies.