Glacier Lakes Ecosystem Experiments Site: An "Experimental" Wilderness

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Abstract--This site, selected to be representative of high-mountain wilderness ecosystems, is being used to study the effects of air pollution and atmospheric deposition in alpine and subalpine, terrestrial and aquatic biotic communities. The research program includes (a) short-term experiments designed to quantify the response of system components hypothesized to be most sensitive to changes in ozone, S, and N air pollution and deposition; (b) development of operationally oriented models capable of predicting system, species, and biogeochemical responses; and (c) long-term biogeochemically-oriented monitoring to help establish the validity of (a) and (b) as management decision tools.

Wilderness is the most rapidly increasing land use within the National Forest System. Wilderness presents a unique set of challenges to managers. To date, management has largely been confined to controlling or minimizing visual effects. However, other stresses are operating in complex ways that cannot be seen. Of particular concern are effects caused by air pollution, and combinations of air pollution and climate change hypothesized to result from increasing human populations. A logical first step in scientifically based wilderness management involves monitoring these ecosystems over time. We have recently developed guidelines for this purpose (Fox, et. al. 1987).

It is well known that ecosystems change in response to natural internal dynamic processes as well as to both natural and anthropogenic external stresses. Our present knowledge of wilderness ecosystems does not allow us to distinguish the subtle differences between these change-causing factors. However, prudent management of wilderness requires that ecosystem effects resulting from changes in the chemical and physical climate be understood. From such understanding will develop management alternatives to help maintain these wildernesses as areas substantially "uninfluenced by the hand of man."

Just as we have learned how to manage commercial forest ecosystems through carefully controlled research studies, so also will we learn to manage wilderness by studying it. The research, however, is different from what has been done in the past. Questions involve sorting out the role of unseen stressing factors, components of the general environment, on ecosystem health. Issues relate to maintaining rare and endangered species where pertinent. Debate about the appropriate manner to gauge ecosystems, whether on a species or a functional level, must be resolved. Ensuring the vast biotic diversity among wildernesses is a new and unprecedented management objective.

These complex questions require research that considers the system from different perspectives. Research will require studying the response of tightly defined ecosystems to atmospheric inputs. Figure 1 illustrates the components of an ecosystem. The boxes represent transfers between components. The challenge in ecosystem research is constructing boundaries around these components that allow a mass balance of fluxing chemicals to be constructed with some accuracy. These "ecosystems" might be an entire watershed, a few tens of meters of a stream, or a very carefully isolated 1 m^2 patch of alpine soil. Common to all these differently defined ecosystems will be the ability to construct accurate nutrient budgets and to study, in a self-contained manner, processes of and interactions between the organisms and abiotic factors that consume, alter, and generate these nutrients. Species and community level dose/response experiments are being conducted to evaluate specific response hypotheses. Process-based models will be constructed to try to incorporate individual responses into system-level behaviors. Long-term monitoring data will be required to ensure the validity of hypotheses and models in the natural landscape.

Conducting such an extensive research program is incompatible with legally mandated wilderness. Rather, a location is required that (a) is not formally designated wilderness but has current and past uses like wilderness, (b) is remote but accessible year round, and (c) contains ecosystems that can be hypothesized to be sensitive to air pollution, acid deposition,

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and climate change. To find the best possible location for this research program, we spent 2 years evaluating potential locations. This involved a large number of scientists and a field season of data collection before the final site was selected.

Selection was based on a set of criteria that included logistical factors (ownership, permission to conduct research, accessibility, historic data) and ecological factors (excellent air quality, alpine/subalpine type, nonweatherable bedrock, lakes, water with ANC < 50 ueq/l, soils with base saturation less than 25%). Ecological criteria were based on the hypothesis that currently unimpacted systems exhibiting low buffering capacity are likely to be maximally sensitive to air pollution inputs. The buffering capacity was gauged by acid neutralizing capacity (ANC) of the surface waters, relative mineral weathering potential of bedrock, and exchange capacity of the soils. An alpine location was desired that collects large amounts of snow. The snowpack effectively accumulates and stores pollution on the site until spring melt. Spring brings a pulse of chemicals delivered rapidly to the ecosystem. This can result in a temporary change in lake chemistry which, depending on lake pH, may cause changes in the biotic complex. Such a location is clearly the most sensitive from an aquatic perspective. In clean air, ozone concentrations tend to increase with elevation. Climate influences are dominant factors in the alpine, tree line providing a dramatic example. It is therefore reasonable to hypothesize that alpine locations will be most sensitive from a terrestrial perspective as well.

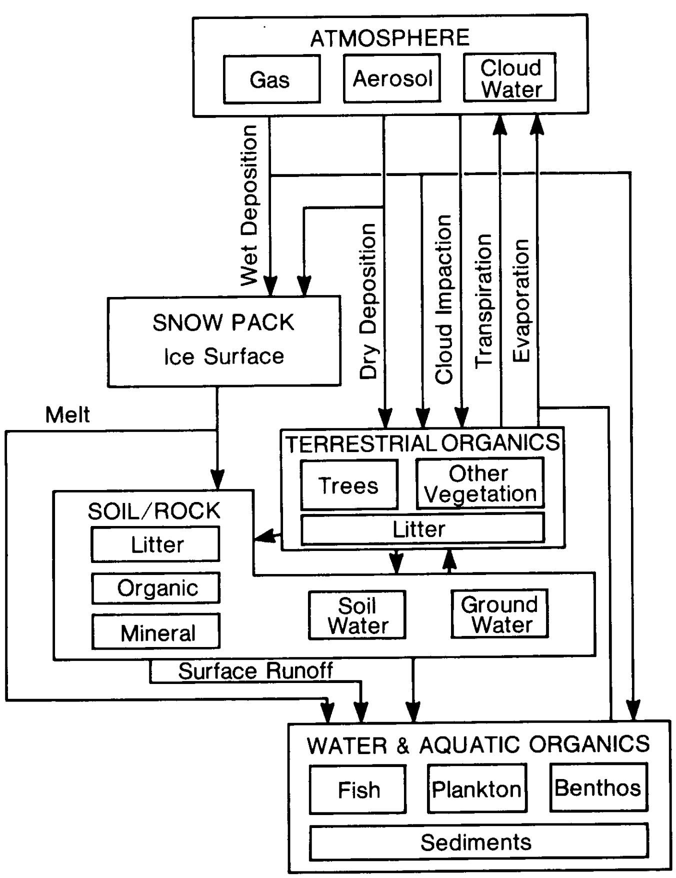


Figure 1.--Box and line diagram of GLEES.

All these criteria are met at the Glacier Lakes Ecosystem Experiments Site (GLEES).The site and the research program currently underway there are described in the remaining sections of this paper.

GLACIER LAKES ECOSYSTEM EXPERIMENTS SITE

Location and Topography

GLEES is located on the Medicine Bow National Forest approximately 65 km W of Laramie, Wyoming. The site is a high (3,400 m) glacial cirque basin, containing three small lake watersheds (104, 52, and 43 ha) fed by first-order perennial streams generated from permanent snow fields (fig. 2). Vegetative cover is primarily subalpine, with a sparse Engelmann spruce-subalpine fir forest (including krummholz stands), forb-dominated snowpatch communities, and sedge meadows. Soils are minimally developed. Geologically, the basin is uniform quartzite (75-80%) crossed by intrusions of amphibolite, a mineralogically complex and active mafic rock. Water chemistry is dominated by snow chemistry except for streams that run through sufficient mafic materials to reflect weathering processes. Lake water is extremely low in ionic strength; alkalinities are on the order of 40 ueq/l.

Meteorology and Air Quality

Data have been collected in the vicinity of the Glacier Lakes since the late 1960's, primarily for measuring the contribution of the Snowy Range to Wyoming water resources (Wesche 1982). Mean temperatures measured near the watershed range from lows of -10° F to highs of 30° F in winter and lows of 20° F to highs of 70° F in summer. Wind speed, on the exposed locations of the watershed, can average above 15 mph for months at a time. Precipitation is highly variable across the watershed but averages 35 inches at Lost Lake, 42 inches between East and West Glacier Lakes, and 49 inches near the East Glacier Lake outlet.

Although no air quality measurements have yet been recorded, the area is assumed to be clean based on the chemistry of precipitation. A wet/dry precipitation collector operated by the Wyoming Water Research Center for the National Acid Deposition Program on the southwest side of West Glacier Lake since April, 1986, indicates sulfate and nitrate concentrations generally below western averages.

Air quality measurements will be initiated on the watershed in 1987.

Geology and Soils

The geology of GLEES has recently been described by Rochette (1987) and the soils by Hopper and Walthall (1987). Local alpine glaciation caused three cirques or nivation basins

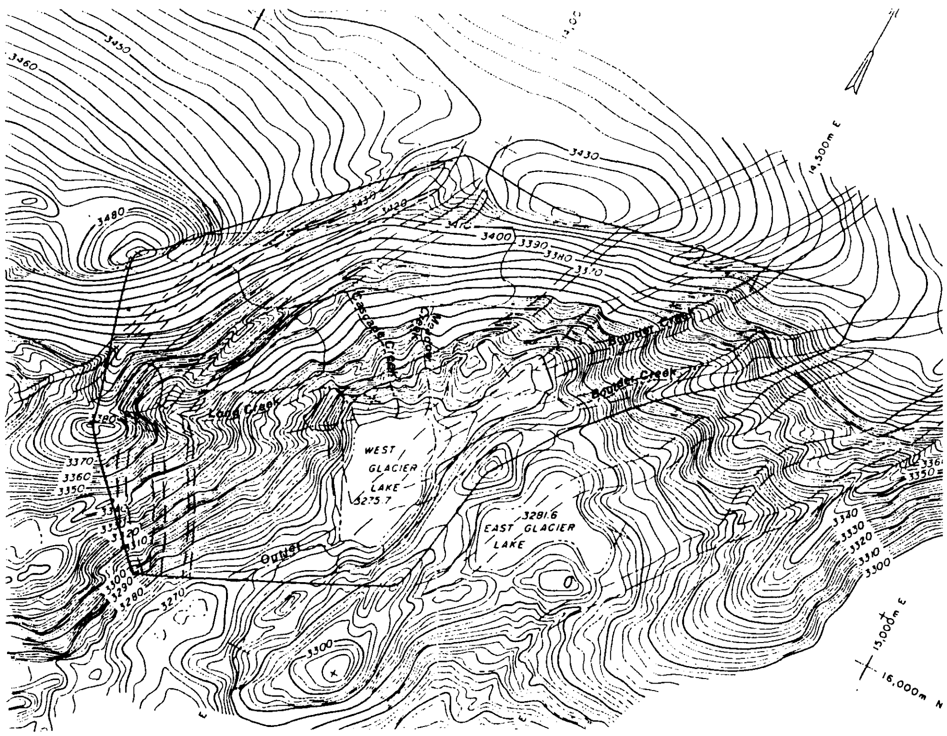


Figure 2.--The GLEES contour and geologic map. Dashed lines illustrate mafic dykes into the surrounding quartzite. The geological mapping is only in the boxed areas.

to form on the south side of the primary ridge line. Bedrock is quite uniform, consisting of Medicine Peak quartzite intruded with 15-20% mafic dykes of amphibolite. The significance of the mafic rock is that it is considerably richer in minerals. The chemistry of surface waters in the streams feeding West Glacier Lakes appears to be dominated by weathering of the mafic rocks. Nevertheless, this weathering rate is not likely to increase with acid deposition, and because of minimal soil-water contact, the watersheds are considered quite sensitive to increases in acid deposition (e.g., the watershed buffering capacity is small) (Rochette 1987).

Vegetation

The watersheds are predominantly subalpine with considerable abundance of alpine taxa (Simmons 1987). The forested areas (35% of the area) are Engelmann spruce- subalpine fir, which also form krummholz stands at more exposed locations (fig. 3). An occasional limber pine can be identified. A total of 135 plant taxa have been identified on the watersheds. Many are alpine species, particularly in the meadow and cushion-plant assemblies. Herbaceous vegetation types (meadows, cushion-plant-dominated ridge tops, and partially vegetated scree) make up 30%, while willow-shrub types (willow and wet meadow willow) comprise the remaining 5%, which is significantly vegetated.

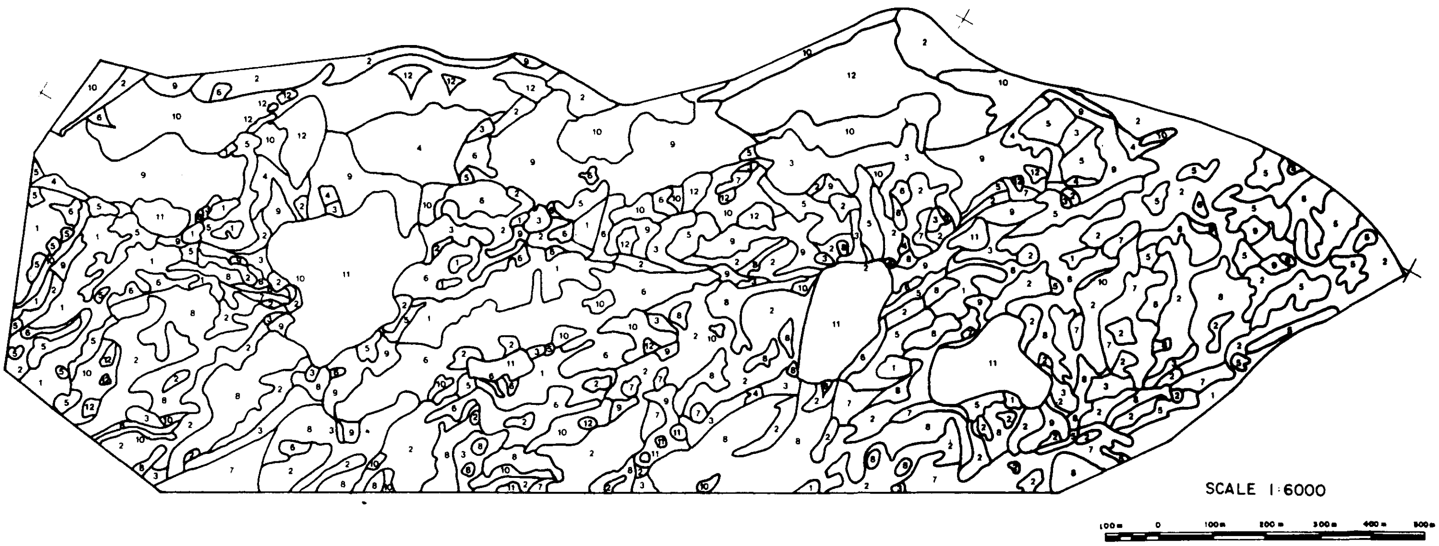
Lakes and Streams

Lost Lake is the largest (6 ha) and highest (3332 m) of the three lakes. East Glacier Lake is 2.8 ha with a watershed of approximately 43 ha. West Glacier Lake is 2.6 ha with a watershed of approximately 52 ha. Four streams, as shown in figure 2, feed West Glacier Lake. Inflow to East Glacier Lake is largely accomplished by nonchannelized flow and therefore, appears to be relatively more subject to interactions with watershed soils and vegetation.

Lakes and the West Glacier outlet stream support brook trout populations. In addition, East Glacier supports a cutthroat trout population. Macroinvertibrate sampling suggests a relatively depopulate community of cold water species in the stream. Lake and stream acid neutralizing capacities are low ranging between 30 and 50 ueq/l.

THE RESEARCH PROGRAM

The site will be used for long-term ecosystem study. The study will be watershed oriented, namely individual watersheds and subcatchments within these watersheds will be identified, gauged, and studied. Figure 1 can be used to represent a simple conceptual model of the GLEES. Our research plans include measurement of the reservoirs and as many of the transfers as are practical. Within this framework,



KEY TO VEGETATION/LANDSCAPE TYPES

1 Cushion Plants/Stone Pavement
2 Meadow
3 Willow Shrub/Wet Meadow
4 Scree/Meadow
5 Krummholz Conifer>60 % cover
6 Krummholz Conifer 20-60 % cover
7 Coniferous Forest>60 % cover
8 Coniferous Forest 20-60 % cover
9 Scree
10 Rock Outcrop
11 Water
12 Snow

Figure 3.--Vegetation and landscape types on the GLEES.

detailed budgets associated with the reservoirs themselves will be constructed. Where possible, paired systems will be identified or constructed so that manipulation experiments can be conducted with controls.

Atmospheric Compartment

The careful measurement of atmospheric input to the GLEES will be a hallmark of this research. In addition to measurements, the Topographic Air Pollution Analysis System (TAPAS), a comprehensive set of meteorologically based state-of-science computer simulation models will be used to help characterize the atmospheric compartment. Specific studies include:

Meteorology.--The objective of meteorological studies is to characterize the overall meteorology and climate of the GLEES. The relatively uniform terrain of the GLEES allows a minimum of measurements to accomplish this (fig. 4). Instrumentation has been installed at two locations on the GLEES. At each a tower has been erected well above the forest vegetation. Both are instrumented with wind speed, direction, temperature, and humidity. Planned expansion includes multiple levels of turbulence and radiation instrumentation.

Air Quality.--The objective of air quality measurement is to help characterize chemical inputs to the GLEES. It is a measure of the amount of chemicals in the atmospheric compartment and helps in the measurement of dry deposition, one of the major unknown transfers from the atmospheric compartment.

Wet Deposition.--The objective of wet deposition measurement is to further characterize chemical inputs to the GLEES. It also is a major transfer from the atmospheric compartment. A wet deposition collector has been operating at the site since Spring, 1986. Additional bulk precipitation samplers will be installed at various locations on the GLEES in order to establish input chemical variances.

Dry Deposition.--The objective of dry deposition research is to try to directly measure this most illusive component of atmospheric transfer. To date no dry deposition measurement has been made in a complex-terrain forested setting.

Snow Pack Compartment

Snow pack is considered a separate component of the ecosystem because of its importance to the collection and delivery of air pollution and deposition to alpine systems. One cubic meter of snow contains approximately 104 square meters of surface area, about 2 football fields. This vast surface area is available to collect and hold pollution. Considerable research on snow chemistry and physics processes is underway within the Atmospheric Deposition Effects research unit. An ambitious field research program centers around an attempt to characterize the rapidly changing chemistry of melting snow.

Terrestrial Organic Compartment

Our interests in the terrestrial compartment are both with the transfer of atmospheric chemicals and nutrients into this compartment and with dose/response studies of selected

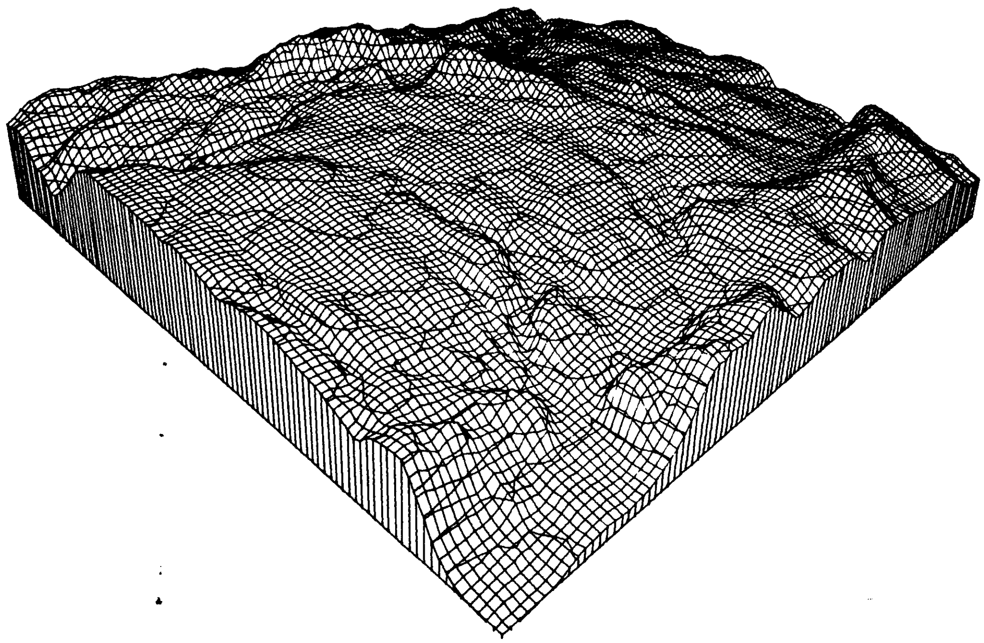


Figure 4.--A three-dimensional perspective of the GLEES vicinity. The maps in later figures cover the boxed area. Centennial is located in the lower corner of the map. The map was produced by the Topographic Air Pollution Analysis System (TAPAS) (Fox, et.al. 1986).

species within this compartment. The objective of this research is to establish the relative sensitivity of the alpine floristic component of the GLEES to air pollution and deposition. The first step in this research is to attempt to use a combination of physiological and morphological information to screen plants for their theoretical sensitivity. This is a field activity that will be conducted at the GLEES. The second step requires manipulation of the "theoretically" sensitive plants by subjecting them to elevated pollution and deposition.

Soil, Rock and Ground Water Compartment

A soil map of the GLEES has already been prepared. The ability of the soil to consume H^+ will be studied using the soil map along with laboratory studies of the soil chemistry such as SO_4 and NO_3 sorption, cation leaching, etc.

Water and Aquatic Organics Compartment

Stream Study

The chemistry and biology of a pair of streams, Cascade and Meadow, will be characterized. One stream will be manipulated by the input of sulfuric and nitric acid. Effects on the stream biota will be measured. This study will utilize the recently constructed gauging stations for each stream, input reservoirs at the stream head, drift nets and emergence traps (houses over stream).

Lake Studies

We also will attempt to characterize the role played by the lake in nutrient dynamics of the system. In addition to the morphometric survey already completed, sediment mapping and coring will be conducted including introduction of a paleolimnological tracer for the future. Seepage meters will be installed on transects in the lake bottom. The Parshall flumes in GLEES will be used to aid careful measurement of the hydrological balance of the watershed.

Fish surveys will be conducted as needed to determine the biomass and condition of this resource. Plankton productivity will be studied with small containers suspended in the lake closed to the system but containing carbon 14. Benthos will be surveyed by scuba divers.

SUMMARY

A broadly based ecosystem research program has been initiated on the Glacier Lakes, Medicine Bow NF, Wyoming. The ecosystem on the Glacier Lakes is alpine/subalpine and in a natural state. Minimal management activity is conducted on this area which is prototypical of much of the Wilderness system in the western US. The Glacier Lakes site can be considered an experimental wilderness. It is expected to exhibit extreme sensitivity to changes in atmospheric inputs of chemical nutrients and energy. The research program planned for the Glacier Lakes will provide new information for managers in the 21st Century. This information is likely to be centered around increased world population and manifested in the form of increased recreational use of areas like the Glacier Lakes, and changed climate as a result of increased air pollution.

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