Physical Environment

Most of Yellowstone National Park lies within one of the world's largest volcanic calderas, which now encompasses the 14-mile width of Yellowstone Lake and is encircled by the park's major geyser basins. During the volcano's last major eruption, about 600,000 years ago, a deep layer of ash settled as far away as Nebraska. More recently, people wondered what sort of biological communities would arise from the ashes left by the fires of 1988, which swept across more than one-third of Yellowstone. Although our knowledge of how Yellowstone evolved after that stupendous volcanic eruption remains sketchy, we have been able to observe firsthand and document in detail what has transpired in the park since 1988. We have seen trees, shrubs, and grasses emerging from the reservoir of seeds, bulbs, and roots that lay within the nurturing environment of Yellowstone's soil. Although the effects of those fires will be evident, visually and ecologically, for decades to come, the "new" Yellowstone is fundamentally a continuation of the "old" Yellowstone—the ever-changing result of fire, climate, geology, and other natural processes that have been continuing for eons.

The Geology of Yellowstone

The oldest geologic materials in Yellowstone are Precambrian gneiss and schists (2.7 billion years old) that can be found in the Black Canyon of the Yellowstone River. Eocene Absaroka volcanics (40 to 50 million years old) buried the region in deposits of andesite lava, ash, mud, and debris flows that are thousands of feet thick on the east and northwest sides of the park. These mud and debris flows buried forests and formed the petrified or fossil forests that are now popular park attractions. More recently, during the last two million years, cataclysmic eruptions created three calderas, including the enormous Yellowstone caldera in the center of the park we know today, and produced extensive sheets of rhyolitic ash tuff and lava flows, the most common geologic materials in the park. The magma under the surface continues to provide a heat source in parts of the park, creating geysers, hot springs, mudpots, and fumaroles, and contributes to the frequent seismic activity in the area. Hidden beneath the region, Yellowstone's volcano is dormant at best; most geologists predict another cataclysmic eruption "relatively soon"—within the next 10,000 years or so.

The area has undergone at least three extensive glaciations, during which glaciers created the landforms and surficial deposits that now dominate the topography. It was at the end of the last glaciation, fewer than 14,000 years ago, that plants and animals returned to the area and the landscape began to look like the Yellowstone we know today.

The Dimensions of Yellowstone

Yellowstone National Park covers 2,221,766 acres, which is roughly the size of the state of Connecticut. Most of the park is located in the northwestern corner of Wyoming, but a small portion overlaps that state's boundaries with Montana and Idaho. The park is comprised primarily of high, forested, volcanic plateaus that have been eroded over the millennia by glaciation and stream flow and that are flanked on the north, east, and south by mountains. The Continental Divide traverses the park from its southeastern corner to its western boundary. The elevation of the park averages 8,000 feet, ranging from 5,282 feet in the north, where the Gardner River drains from the park, to 11,358 feet in the east, at the summit of Eagle Peak in the Absaroka Range.

Restoration of Mining Sites

The U.S. Congress agreed to the boundaries of Yellowstone National Park in part because the area was thought not to include any significant mineral deposits. However, sand, gravel, and rock were once excavated for road construction in the park, and some coal mining was done during the World Wars. As a result, the park's landscape is marred by excavation pits and mine entrances in certain areas. In the early 1990s, Yellowstone began working with Wyoming and Montana to obtain state mining reclamation funds that were intended to be available for this purpose. A small coal mine on McMinn Bench with an open entrance and unsightly, unvegetated tailings was rehabilitated in 1993. Three gravel pits (Little Thumb Creek, Dry Creek, and Ice Lake pits) were restored in 1997 and, with funding provided by the state of Wyoming, work on other abandoned mine sites is expected in the future.

Soil survey. After eight years of data collection and analysis of samples from more than 1,200 sites, a comprehensive survey of Yellowstone's soils was completed in 1996 in cooperation with the Gallatin National Forest. This information is valuable to the understanding of a wide range of phenomena, including erosion, flooding, and sedimentation processes, and revegetation after fire, grazing, natural perturbations, and human-caused disturbances.

Surficial processes. Despite the soil survey, information about the geologic processes that take place in streams and on the landscape, and how our activities affect them is still inadequate, partly because of the lack of staff specialists. Park managers must routinely make decisions affecting location of roads, rip-rap, and septic systems; stream and lakeshore erosion, fire-related sedimentation, and vegetation-geology-animal relationships, without comprehensive geologic information. Additional scientific knowledge and long-term experience are necessary to improve management decisions in these areas.

Geothermal Features

Within Yellowstone's boundaries can be found more than two-thirds of the world's geysers, along with about 10,000 hot springs, mud pots, and fumaroles. The only other major geyser basins that have not been disrupted by human activity lie on the Kamchatka Peninsula in eastern Russia. The park's steamy geology also supports the world's most visible concentration of heat-loving bacteria, known as thermophiles. Researchers have focussed on these unique life forms because of their ability to survive in very extreme

conditions, and their contribution to major advances in medicine and biotechnology. (See "Bioprospecting," page 5-7.)

Although Yellowstone's geothermal features are the most unique of its natural resources—and among the most vulnerable to human activity—they receive a very small portion of the park's funding for research and monitoring. This is partly because the charismatic wildlife species generally dominate the attention of the public and special interest groups, to whom threats to geothermal resources are often invisible.

An underground internet. Yellowstone's geothermal features are part of a complex hydrothermal system that extends well beyond the park's boundaries, especially to the north and west. Thermal features can be extremely sensitive to natural or human-caused ground disturbances, and alterations to any of the system's components could have far-reaching consequences. Certain types of deep drilling or thermal resource development could introduce new water or flow paths, change the pressure in the system, or remove heat from it. Even relatively small changes in subsurface reservoirs may affect surface features that are miles away. The effects may be seen immediately or many years later, but once a change occurs, restoration of a feature's original function is generally impossible. In Iceland, New Zealand, Chile, Japan, and the United States, geothermal drill holes and wells up to 30 miles away have greatly reduced geyser activity and hot spring discharge.

A major threat to Yellowstone has come from proposals for geothermal lease applications for sites outside the park, some less than two miles from known park thermal areas. Commercial facilities could, for example, use steam trapped underground to drive electrical generators. Although geothermal test drilling outside the park in 1986 prompted a round of studies, funding has never been available for the long-term databases needed to accurately assess the geologic hazards and potential effects of external drilling activities on park resources. Scientists caution that external drilling for oil and gas development would be even more of a threat, because the extraction of fluids can cause subsidence and earthquakes, which typically result in changes in geothermal features.

Montana / NPS Reserved Water Rights Compact. After a decade of negotiations, the NPS and the state of Montana signed an agreement in January 1994 to guarantee that Yellowstone's historical water rights will not be violated and that geothermal aquifers with potential connections to Yellowstone's geyser systems will not be compromised. The agreement quantified Yellowstone's water rights (see "Lakes, Streams, and Groundwater," page 2–17) and set up a process to protect these rights from outside development. Under traditional water law, the burden of proof would have been on the NPS to demonstrate that a development would cause impairment. Even if such proof were possible, by the time the impairment to a thermal feature was apparent, it would have been too late to rectify. The compact addressed this issue by requiring the developer to demonstrate that no potential exists for adverse effects to the hydrothermal system and that any scientific doubt concerning the effects will be resolved in favor of hydrothermal protection for the park. A technical oversight committee of scientists with hydrothermal system expertise has been established to review the evidence.

Dangers and Discoveries Atop the Volcano

Yellowstone has one of the largest semi-dormant calderas in the world, measuring 47 miles long and 28 miles wide. The last cataclysmic eruption, which expelled more than 240 cubic miles of lava, rock, and ash, was part of a volcanic period that began about 650,000 years ago. Major hydrothermal explosions were still taking place about 3,500 years ago, which in geologic terms is just yesterday.

The University of Utah operates a network of 22 seismic stations in and around the park to gauge the magnitude of earth tremors. A swarm of more than 100 small earthquakes was reported west of Norris with magnitudes up to 4.3 on the Richter scale during the summer of 1997 and again in September of 1998. Such swarms happen frequently in greater Yellowstone, which was rocked by earthquakes of 7.0 or greater in 1959 and again in 1983.

Yellowstone's many geothermal features are extremely sensitive to seismic processes; small and large tremors often affect the activity of geysers and hot springs, making each visit to the geyser basins as unpredictable as a hike in search of wildlife. The Yellowstone hot spot also presents significant human safety hazards—potential volcanic eruptions, hydrothermal explosions, and earthquakes—and an opportunity to study and possibly predict major geologic activity. We expect that future volcanic unrest will be preceded by far more intense seismic swarms and hydrothermal changes.

Geologists survey volcanic uplift within the Yellowstone caldera on an annual basis. The total uplift from 1923 to 1984 was about one yard; then the caldera subsided about an inch each year until 1996, when it began to move upward again. To detect potentially hazardous changes on a day-to-day basis, a network of six automated gauging stations was installed at Yellowstone Lake in 1983, but they are no longer in operation due to lack of funds.

A Breath of Fresh Air

Under the Clean Air Act, Yellowstone is designated a Class I airshed—intended to have among the cleanest air in the United States. While the park's isolation from urban and industrial areas provides a buffer from major sources of air pollution, research in many ecosystems has shown that airborne pollutants affect air quality and visibility hundreds of miles away.

Baseline air quality sampling in Yellowstone began in 1980 with the installation of equipment to monitor wet deposition (precipitation volume and chemistry) at the Tower Ranger Station as part of a National Atmospheric Deposition Program. Visibility is monitored at an IMPROVE (Interagency Monitoring of Protected Visual Environments) station near Lake Yellowstone. An EPA-coordinated CASTNET (Clear Air Status and Trends Network) station measures atmospheric concentrations of sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid as well as ozone and meteorological factors such as air temperature, solar radiation, wind speed, and direction. Montana monitors carbon monoxide at the park's West Entrance. The results indicate that the park's air quality and visibility generally remain high, but site-specific problems exist.

In Yellowstone, the most pressing concern is snowmobile exhaust from within the park (see "Winter Use," page 6–38). In the winters of 1993 and 1994, the park began to document the physical symptoms of employees at the West Entrance, where more than 1,200 snowmobiles come through on a peak day. Snowmobiles are powered by two-stroke engines that have high power-to-weight ratios and operate well in sub-zero weather but are inherently polluting; one-quarter to one-third of the oil and gasoline mixed in the combustion process is emitted unburned. Snowmobiles produce significantly more carbon monoxide and particulates than the modern automobile, and their emissions may contain significant quantities of toxic air pollutants.

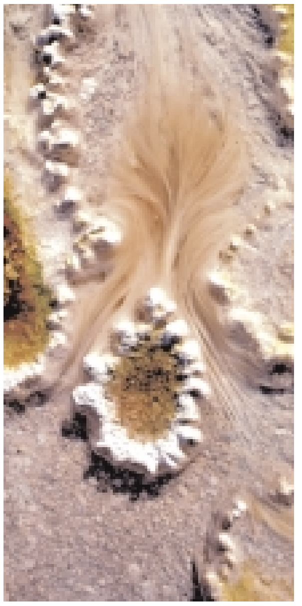
Recent modifications to the kiosks and park operating procedures appear to have reduced exposure to snowmobile exhaust for employees at the kiosks. Unanswered questions about the effects of snowmobiles and automobile exhaust on visitors, employees, and the ecosystem's natural and cultural resources make monitoring and interpretation of Yellowstone's air quality a continuing necessity.

Program Needs

• Legislative protection. The policy on federal land has been to reject geothermal leasing applications "until adequate safeguards for protection of surface resources may exist as a result of developing technology." But a shift in energy economics could increase interest in opening non-federal lands to drilling activity. Legislation passed by Congress in 1988 requires the Secretary of the Interior to prevent geothermal development on adjacent federal lands that would affect geothermal features in national parks. In 1991 and again in 1993, a bill called the "Old Faithful Protection Act" was passed by the U.S. House of Representatives. The bill would have required developers of any land within 16 miles of the park to prove that geothermal drilling would not harm Yellowstone's hydrothermal system. Despite the support of governors from all three surrounding states, the bill did not pass the Senate in either year, and there are no proposals to reintroduce the legislation.

Although the Montana/NPS Reserved Water Rights Compact addresses important groundwater development issues, it does not cover the direct extraction of heat, steam, and geothermal brine, and it includes only Montana, not Idaho or Wyoming. To ensure the integrity of Yellowstone's geothermal features, the NPS has recommended that Congressional action be taken to control groundwater development adjacent to the park in Wyoming and Idaho. Protection should extend to the cold water influx as well as the hot water outflow. Other activities such as the extraction of heat, steam, and geothermal brine should be controlled in all three states adjacent to the park.

• Inventory. Inventory and monitoring of the park's air quality, geothermal, seismic, and hydrologic resources have been suspended or seriously curtailed during the last decade because of funding constraints. Only 40 percent of Yellowstone's 121 known geothermal areas have been thoroughly mapped and documented through measurements, photographs, and chemical analyses; 30 percent are partially inventoried; and the remaining 30 percent have not been inventoried at all. The locations of previously disturbed sites such as gravel pits, closed landfills, abandoned development sites, and rerouted roads are known but need to be mapped, catalogued, and prioritized for restoration. Funding is needed to complete thorough inventories of geological resources, make such data readily accessible, and to implement a systematic program to rehabilitate disturbed lands.



• MONITORING. More systematic monitoring of thermal resources, especially hot water discharge, is needed in order to recognize and interpret changes in geothermal features as they relate to natural or human-caused events. At present, only Old Faithful is continuously monitored. Professional monitoring is also essential at disturbed sites, particularly those having hazard potential such as landfills and sites near streams, as they are reha-bilitated. Monitoring should continue until it can be confirmed that there is no ongoing environmental degradation. A comprehensive winter air quality monitoring program is needed to better identify pollutants in high-use snow-mobile areas, measure the exposure of employees and visitors to the emissions, evaluate potential health effects, and measure pollution deposition in the snowpack and runoff.

• STAFFING. Following the loss of the park's only geologist, who died in 1997, an advisory group of physical scientists recommended that three positions be established for earth scientists to monitor geophysical resources and processes, address threats to water quality, interpret air-land-water relationships, and bolster the park's efforts to interpret its unique geology. But tight budgets prevented any new geologists from being hired until late 1999.

• RESEARCH. More research is needed to better understand geothermal systems, identify and plan for potential geothermal and seismic emergencies, and assess the effects of external activities such as oil and gas drilling. Although current funding permits operation of six U.S. Geological Survey gauging stations located on each of the main river systems exiting the park, additional monitoring stations are needed in order to relate changes in water and mineral data to natural or human-caused changes in aquifers that could affect the park's geothermal systems.

• UPGRADE EQUIPMENT. With rapid changes in seismic and geothermal technologies, the park has been unable to maintain up-to-date monitoring equipment. For example, immediate notification of seismic activity is essential for reporting hazards to park managers and state and local emergency planners, yet the park lacks an immediate communications link with the University of Utah's seismic unit. Portable ambient air quality monitoring equipment is needed to supplement the existing regional monitors permanently located at Lake and Tower Junction. In addition, a regional airshed model needs to be developed and maintained.

Air, Soils, and Geology

Stewardship Goals

Geology and geothermal fearures are completely inventoried, monitored and interpreted using up-to-date information, facilities and techniques.

Air quality is maintained to natural standards for future generations. Public expectations for cleanliness and quiet are achieved.

Water quality and quantity are monitored and national standards are maintained unimpaired for future generations.

All previously disturbed lands not used for visitor or park facilities are restored to natural conditions.

Professional staff implement a fully funded program to monitor and interpret physical resources, and to manage hazards.

Current State of Resources/Programs

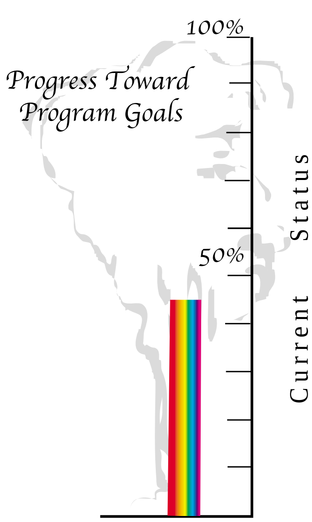
Soils and landforms have been mapped, but less than 30% of geothermal areas have been thoroughly inventoried. Geology interpretation needs updated information, exhibits, and techniques.

Parkwide air resources are fairly pristine. In certain locations, the problem of snowmobile and automobile exhaust needs to be addressed.

Both thermal and cold waters have some protection, but geothermal development poses a serious risk to park resources.

Partnerships and special funding have permitted several disturbed sites to be restored, but dozens remain to be done.

Monitoring and research are undertaken by generous cooperators, but as of late 1999 the park had no geologic experts on staff to monitor resources or hazards.



1998 Funding and Staff

Recurring Funds Yellowstone N.P. Base Budget	$ 200,165
Non-Recurring Funds One-time Projects	$ 36,500
Staff	0.65 FTE

The human resources and funding necessary to professionally and effectively manage the park to stewardship levels will be identified in the park business plan.