The Snows of Yellowstone

by Phil Farnes

Snow and winter are considered by many to make for a miserable time of the year, something that we could live without. Yellowstone National Park is often referred to as a cold, frozen wasteland in the winter. In reality, winter and its associated snowfall in Yellowstone National Park are an essential part of this ecosystem.

There have been significant efforts to monitor snow and understand its influence on park resources and ecosystem processes. One of my particular interests has been in how snow influences wildlife, and how changes in the forest canopy influence the snowpack and runoff from mountain watersheds.

Photo by Ward McCaughey

The author preparing to take a snow core sample.

Yellowstone's Snow Database

Data on Yellowstone's snow comes from several sources. The weather station at Mammoth has one of the longest records in the west. The U.S. Army started collecting daily data on precipitation and temperature in 1889 and the weather station still reports daily values for precipitation, maximum and minimum air temperatures, snowfall, and snow depth. Similar measurements are made at many occupied areas around the park. Collection of data from these sites is coordinated and archived by the National Weather Service.

Snow course measurements in the Snake River drainage of the park were initiated in 1919 at Aster Creek, Coulter Creek, Lewis Lake Divide, and Snake River Station to assist in operating the dam on Jackson Lake. Other snow courses were established in the 1930s. Manual measurements of snow depth, snow water equivalent, and snow density are usually made on the first of January, February, March, April, and May each winter. These are reported to and made available by the Natural Resources and Conservation Service (NRCS), formerly the Soil Conservation Service (SCS). In recent years, automated SNOTEL (Snow Survey Telemetry) sites have been installed at some of these locations to report daily values year-round for snow water equivalent and precipitation, as well as maximum, minimum, and average air temperatures.

Remote Area Weather Stations (RAWS) are relatively new and are primarily used for fire weather. Precipitation, temperature, wind, solar radiation, and relative humidity are commonly collected parameters, however, some of these may not be available during winter. RAWS data are available through the Fire Cache at Mammoth.

Many short-term measurements have been taken at weather monitoring sites in and near Yellowstone National Park and at many other locations. These records are available in the park and from NRCS.

Seasonal and annual precipitation is quite variable across Yellowstone. About 30 to 35 percent of annual precipitation occurs as snow at lower elevations and up to 70 percent falls as snow at higher elevations. Average annual precipitation varies from about 11 inches at the North Entrance to more than 70 inches in the higher elevations of the southwestern part of the park. The deepest snow depth measured at a snow course was 167 inches at Lewis Lake Divide. An aerial observation of 211 inches of snow depth was recorded at the Pitchstone Plateau aerial marker. The average annual precipitation for Yellowstone is about 39 inches. Individual years can be as low as 60 percent to as high as 150 percent of the long term average.

From Snow to Water

Snow that accumulates across the higher elevations during winter and early spring provides snowmelt runoff during the growing season. This water supports significant downstream recreation, agriculture, and industry, as the park and surrounding mountains are the headwaters of Yellowstone, Madison, Gallatin, Snake, Shoshone and Falls rivers. Water from the melting snow percolates into underground channels and recharges the soils, as well as the thermal areas and storage areas for springs and seeps. High spring flows carry sediment downstream, redistribute gravels, and maintain creek and river channel configurations.

Growth in most plants is not initiated until snow disappears in the spring and air temperatures exceed biological zero (usually considered to be about 41°F or 5°C). Some shrubs may initiate growth when their crowns become snow-free and air temperatures warm enough to induce plant growth. At higher elevations, the year-to-year variation in when an area becomes snow-free may vary by as much as six weeks. Soil moisture along with warm temperatures and nutrients in the soil enables plants to grow. Trees, grasses, shrubs, and forbs are all dependent on this annual supply of moisture. These plants support an extensive insect and animal biomass which, in turn, are partly controlled by snow and winter.

Most scientific studies use Snow Water Equivalent (SWE) as it better represents the true measure of the snowpack than does snow depth. One inch of SWE equates to one inch of precipitation. Newfallen snow has a density of 5 to 10 percent. This means that it takes 10 to 20 inches of new snow to yield one inch of SWE. As the snowpack goes through various transformations, the density of snow increases up to 25 to 30 percent prior to melt. During this time, it takes only three to four inches of snow to yield one inch SWE. The density depends on depth of the snowpack and winter temperatures. Deeper snowpacks are more dense, as the internal weight of the snow creates additional compaction. Deep snowpacks and wind-deposited snow may reach densities of 45 to 50 percent late in the melt period.

The largest measured SWE was 76.0 inches at Lewis Lake Divide snow course on April 16, 1927. Other high SWEs recorded in greater Yellowstone include 66.6 inches measured at the Black Bear snow course on the Madison Plateau just west of the park and 65.6 inches at the Fisher Creek snow course near the northeast corner of the park in the Beartooth Mountains.

Tidbits to Know About Yellowstone Snow

❄ Snow has many different forms—it may fall as sleet or soft, light flakes. It changes structure from the time that it falls until it melts.

❄ Arctic storms usually deposit small amounts of snow but have very cold temperatures. Storms approaching Yellowstone from the west or southwest usually have moderate to warm temperatures and deposit heavy snowfall at higher elevations.

❄ During non-snowfall periods with very cold air temperatures, moisture vapor leaves the snow pack. This can leave a very weakly structured snowpack often referred to as "sugar snow." This depth hoar or temperature-gradient snow may dominate the lower half of shallower snowpacks. This condition often causes high avalanche danger. It also affects forage availability for grazing animals.

❄ Snow affects wildlife we seldom see or think about in winter. Spawning success of cutthroat trout can be affected by streamflow generated by the winter's snowpack. Very high streamflows can wash out redds, while very low flows may dewater redds and enable water temperatures to rise to less desirable levels. Sediment transported by high streamflows may also affect egg development in redds.

❄ Snow insulates the soil from severe air temperatures. Typically, soils do not freeze under snowpacks that are deeper than 2 1/2 feet. This allows meltwater to percolate into the soil and subsurface zones rather than run off over a frozen layer. This also allows small mammals to burrow and forage in the soil near the snow surface throughout the winter. The insulation provided by the snow protects plants and other organisms from the severe temperatures that occur above the snow profile.

In spring, snow melt usually occurs for only four to six hours during the day. This extends the period that snow remains on the ground. Lower elevations start to melt while higher elevations continue to accumulate snow. As higher elevations start to melt, lower elevations become bare. This sequence helps spread the snow melt over a three to four month period. However, cool spring weather can retard early season melt; then when the weather warms, all elevations may contribute melt water. This was very evident in the spring of 1996, when record levels of streamflow occurred under conditions of heavy, late-season snowpacks, despite very little contribution from spring rains.

The 39 inches of average annual precipitation across Yellowstone produce about 18 inches of runoff. About 3.3 million acre feet of water flow out of the park in an average year. The runoff in any individual year may be as low as 1.6 million acre feet or as high as 5 million acre feet. Yellowstone Lake may reach a summer high level of more than seven feet on the Bridge Bay staff gauge in heavy snowpack years, but may reach only two feet in low snow years.

Effects of Snow on Wildlife Foraging and Movements

Snowfall in the autumn and early winter prompts animals to migrate to lower elevations where forage is more available. During years of lower snow accumulation, most of the elk on the northern range winter within the park. In heavy snow years, more than one-half of the northern elk herd move out of the park in search of available forage. I have compared the location of elk during aerial counts from 1968 to 1981 with estimated SWE across the northern range, and it appears some family groups of elk have low tolerance for snow and will migrate early. Others seem to have a greater tolerance of snow and will stay in an area until the snow levels become intolerable. This may be confounded by social intolerance that affects the animals' movements. For example, when high-elevation snowfall causes herds of elk in the upper elevation to move, elk at lower elevations may be displaced to reduce competition for food and social conflict. This may prompt elk

Approximate Bearing Pressure Exerted by Various Animals	
Species	**Walking Pressure Pounds/Sq. Inch**
Bison	21
Elk	21
Moose	17
White-tailed Deer	10
Mule Deer	9
Grizzly Bear	6.7
Black Bear	5
200-lb. Human in Hiking Boots	5
Mountain Lion	2.8
Coyote	2.7
Wolf	2.5
200-lb. Human on Skis	1.1
200-lb. Human on Snowshoes	0.7
Snowshoe Hare	0.4

at the lower portions of the northern range to migrate before any significant snow accumulates in their area.

Small animals and predators generally exert much less pressure on the snow and consequently do not sink as far into the snow as larger hoofed mammals. This enables the lighter animals to easily maneuver across the snow surface when conditions are favorable. Bigger, stronger animals such as bison can travel and forage in deeper snow than can deer or antelope. Comparisons between aerial elk observations and SWE, and snow measurements made on the northern range over the past few years indicate elk and bison generally winter in areas where there is less than 6 inches of SWE, providing they can move to areas with less snow. This translates to as much as 30 to 40 inches of snow depth in early winter, but only 20 to 25 inches in late winter or early spring when snow is denser. When SWE exceeds these levels, it is difficult for elk and bison to obtain forage and travel is more arduous. Prolonged exposure to deeper snowpacks, particularly when accompanied by cold air temperatures and limited forage, may result in mortality. Animals that feed primarily on shrubs or willows are affected more by snow that impedes travel and less by snow that covers their forage.

Snow under a dense, mature, lodgepole pine forest has about one-half the SWE of snow in an open area. Typically, the density of snow in the forest is less than in open areas. Thus, it may be advantageous for large ungulates to use forested areas for traveling (less snow), whereas smaller animals with less bearing pressure may be able to travel more easily in open areas (greater snow density). Wind, rain, or melt crusts, and depth of new snow may also affect animals' ability to travel and forage. During most winters, the snow remains powdery until mid-March, but occasionally mid-winter melt and/or winter rain followed by very cold temperatures can have a major impact on grazing animals' ability to obtain adequate forage. Also, snow moved by foraging animals "sets up" and may preclude animals from using forage below these feeding craters until snow warms near spring.

The bearing pressure exerted by different animals varies widely. Currently I am developing a relationship between sinking depth and snow depth, SWE, and density for all ranges of bearing pressure. This will make it possible to estimate how far any size animal of any species will sink in any snow pack when traveling. The large variation in bearing pressure explains why some animals sink well into the snowpack and others barely sink into the surface. Where animals frequently travel the same route, packed snow will support the animals' weight while using these trails.

Changes in Snowpack Since the 1988 Fires

Many measurements were made after the fires of 1988 to quantify changes in snowpack as a result of canopy burn. Relationships between habitat cover types, canopy overstory measured with the photocanopiometer, basal area, densimeter measurements, and SWE were compared to measurements made in other non-fire areas. These relationships were then used to evaluate changes in hydrology and snowpack.

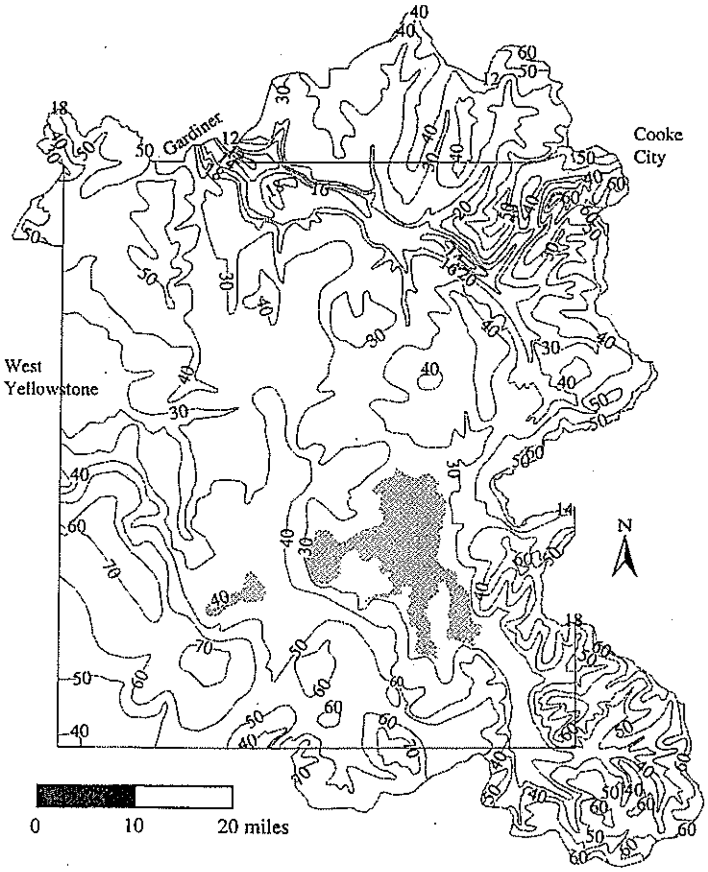
Water yields increased after the fires of 1988. When trees are removed from the system by insects, fires or cutting, the loss of tree canopy enables more snow and rain to reach the ground, which in turn creates more streamflow. Canopy burn occurred on about 20 percent of the Yellowstone area. Studies of the impact of the 1988 fires indicate an average annual water yield increase of about 6 percent or 200,000 acre feet-per-year for the area within Yellowstone National Park. This increase is relatively small; annual variation, may be as low as 50 percent or as high as 150 percent of average. As the burned forest regenerates, the increase in water yield as a result of the 1988 fires will gradually decrease to pre-1988 levels in about 100 years.

Winter travel routes used by elk were probably altered by the fires of 1988. Travel routes through lodgepole pine forests that burned now retain nearly twice as much snow. This forces the elk to find other routes in timber or to move through the burned area before snow becomes deep.

An Index of Winter Severity

Various environmental factors affect wildlife during winter—availability of forage, amount and condition of snow, and air temperature are among the most common. Different wildlife species may react differently to these variables. Conditions may also differ among adjacent winter ranges due to different weather patterns. In general, low-snowpack winters permit animals to use more of the winter range, whereas winters with heavier snowpacks concentrate animals in smaller areas, thereby reducing the area where forage is available.

I used data from snow courses in and near Yellowstone National Park to represent the snow variable on the winter ranges. First-of-the-month SWE, from January 1 through April 1 is used to quantify the winter snow variable. Higher values of SWE indicate a more severe winter. Different methods have been used to represent winter severity. Usually these indices include temperature and a measure of snowfall or winter precipitation and portray severity as a departure from average winter conditions. Although mean monthly temperatures, monthly snowfall, or precipitation are often used



Map showing average annual precipitation, 1961-1990

in these methods, such "mean" data are not always indicative of the stresses that are imposed on wildlife. About nine years ago, I developed an *Index of Winter Severity* (IWS) to help wildlife managers and the public gauge winter severity for wildlife. The IWS is calculated on January 1, February 1, March 1, and April 1 for the winter through these dates. Currently, IWS values are calculated for elk on four segments of the northern range and two segments in the Madison River drainage.

When minimum daily temperatures are below the effective critical temperature, (the animal must increase its basal metabolic rate to maintain its body temperature), from either forage intake or fat reserves, when the temperature is above the critical temperature, the impact to an animal is assumed to be minimal compared to the stress they experience during colder periods. The critical temperature threshold is different for each species, with that for elk being around 0°F (-18°C). Accumulated sums of the daily minimum temperatures below the critical temperature are tabulated for each month from October through March. Larger values of accumulated temperature indicate a more severe winter.

Precipitation at climatological stations for June and July for the previous summer is used as a relative index of forage produced on the winter range. Typically, soil moisture in April and May is high from spring rains and snow melt and is not a limiting factor for forage production. However, precipitation in June and July can limit the amount of forage produced. Less summer precipitation (hence less forage production) indicates a more severe winter.

An index is calculated for each variable based on the probability of non-excedence and scaled from -4 (most severe) to +4 (least severe). Each variable is then weighted to determine IWS. For winter ranges in and near Yellowstone National Park, the IWS for elk is calculated by assigning the snow variable a weight of 40 percent, the temperature variable 40 percent, and the forage variable 20 percent.

Positive values generally indicate only minor effects on wintering wildlife. IWS values from 0 to -2 indicate some influence on reproduction and minor mortality. Values below -2 usually indicate significant mortality and poor survival of young born in the spring. The IWS can be used to evaluate subtle effects on wildlife—those that are not as visible as mortality, but do affect reproduction and survival of young animals. There also appears to be some relationship between winter severity and the success of predators, the availability of game animals to hunters outside the park, and migration responses during different winter conditions.

Animal populations fluctuate in relation to winter conditions. However, large animals such as elk and bison are fairly well adapted to surviving Yellowstone's severe winters. Excluding human-caused mortality factors, over the past 50 years both elk and bison populations on the northern range have increased an average of about 15 percent per year. At these rates, populations subjected to only natural mortality double about every 5 years.

I would like to develop an IWS for bison and possibly other species, modify the temperature variable to weight the effects of temperature according to fat reserves, and possibly modify the forage variable to incorporate the soil-moisture deficit and growing degree-days during the growing season. In addition, a spring severity index to indicate survival of the young of the year could be incorporated into the IWS to evaluate population dynamics. I would also like to see a complete climatic data base developed for Yellowstone where all of the records are on file at one location and where all missing values have been estimated. This data base would be a very valuable resource that would be readily available to future researchers.

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NPS photo

The Biology of Time

Looking at Landscape Changes Through a Photo Series

Dr. Mary Meagher began her long association with Yellowstone as park naturalist (curator) in 1959. Wildlife was always her interest, but her first NPS job offer was as a clerk-typist at Mount Rainier National Park because "with a Master's degree in hand, I would do a perfectly superb job of filing the natural history observation cards. There was one glitch: I couldn't pass the typing test. I resolved then and there I was never going to learn to type." She later accepted a job as a seasonal interpreter at Zion National Park. After being told by a chief naturalist in Yellowstone that he wouldn't hire her because she was female... "To his dying breath, he always referred to me with an appropriate tone of voice as that woman.*" This attitude did not deter her from pursuing a career as a research biologist, completing her Ph.D. at the University of California at Berkeley under the late Starker Leopold. For most of her career she has focused on the subject of her first book,* The Bison of Yellowstone National Park. *In the late 1970s and early 1980s she supervised the park's [former] research division before returning to her own studies in 1983. In August 1996, we spoke with Mary about one of her long-term projects—the use of old and recently re-taken photographs to compare changes in the Yellowstone landscape over its 125-year history. She and co-author Dr. Douglas Houston (who studied ungulates in Yellowstone from 1970 to 1980 and retired in April 1997 from Olympic National Park) present a series of their comparative photos in a new book* "Yellowstone and The Biology of Time," *to be published in spring 1998 by the University of Oklahoma Press.*

YS: Your early years in Yellowstone were an important time of change for the National Park Service (NPS), weren't they?

MM: The 1960s was a period of lots of controversies, lots of vituperation. It was my first exposure to mob violence, which by now seems rather tame, but listening to people in the drugstore in Gardiner ranting about killing park rangers was a new experience for me. All of this was a spinoff from the elk reductions. My memory suggests that perhaps we were on the verge of Congressional action that would allow hunting in Yellowstone. The state of affairs was generated by a long history of concern about the elk on the northern and Gallatin ranges. Based on the prevailing range management perspective, the concern extended to bison numbers parkwide; there were some memos that, to paraphrase, said: "I think there is a problem, and if there's a problem we should have target numbers, which we should evaluate." In a couple of years, things like trial numbers and evaluation sort of got lost—everyone assumed these were hard and fast numbers for which there was a lot of supporting data, and there wasn't.

Basically the plan was to build a science program—not initially a "policy of natural regulation"—it was more a moratorium: "Let's see what our database is that will support the ungulate reductions." And there really wasn't any. That was not deliberate on anyone's part; a lot of very hard-working and well-meaning people committed themselves—lots of personal strength, lots of backbone—to what they felt was the direction to go with the reductions. The National Environmental Policy Act hadn't been passed—there were a lot of things in transition in that mid-sixties period. We'd never survive a similar program without an Environmental Impact Statement (EIS) process now. It was very much a period of learning for us, and because of the impetus to establish a science program we fortunately had some very good people, in certain positions all at the same time—the combination of Jack Anderson [park superintendent from 1967 to 1975], Glen Cole [supervisory research biologist], and Nathaniel Reed [Assistant Secretary of the Interior]...it was a superb time that I have not seen since, frankly. I think the sum was much more than its parts. The park's data was good enough so that the elk reductions could be treated as experimental management by Doug Houston, even though they weren't planned that way. That has given us a lot to work with for both elk and bison, in terms of evaluating where we are today.

YS: So much is made today about the implications of the 1963 Leopold Report. It's always interesting to me to hear from people who were in the parks at the time when the report began to be implemented—it doesn't quite sound the way the history makes it, as though one day the pronouncement came: here was the new policy. Do you think that Starker Leopold and the other members of the Leopold Committee really had any intent or idea that their recommendations would be interpreted so often and so widely as they are?

MM: No, no, no—it was a period of desperately sort of holding the fort, and haunted by the possibility of public hunting in the park. We were all something of a product of the time. I think the whole Leopold Committee was still more deeply into the idea of manipulation than some of our present data tell us we need to be. Call it the "state of the knowledge."

I'd been in Berkeley—Starker was my major professor; I think I was the only woman Ph.D. student he ever had. Starker wouldn't have expected to be quoted that way—he might have spent a little more time picking and choosing his words. We stayed good friends until his death. He'd come up for fishing every year. I asked him if he had said what is in quote marks in Alston Chase's book, *Playing God in Yellowstone.* Starker laughed and said, "Well, you know, Mary, I might be getting a little senile, but I don't recall ever talking to the man." That was my thumbnail sketch of *Playing God*—lots of quote marks, but what was in the book was not quite what was purported to have been said.

Starker was an absolutely superb conservation politician, and I think he did Yellowstone a great service through that period. I wish now we had talked more about some of the politics—you always think you're going to have more time than you ever do. I wish Starker were here in our present post-fire research period to kick some of that new research around.

YS: Tell us about how you started your bison research. Was there a research department in the park?

MM: No, no. I was still a park naturalist. The NPS is a people agency, but the Leopold Report and the Robbins Report [convened by the National Academy of Sciences] were saying we must do better science, and I was in the right place at the right time. I was laying groundwork to go back to school. I remember contacting the Craigheads [researchers working on grizzly bears in the 1960s]—I knew John Craighead slightly from the time I went to school in Missoula—and I was interested in what they were doing with bears. I compare my background in most of what I've learned about human behavior as parallel to what I've learned about brucellosis—I know more about both of them than I ever wanted to know. John assured me that they'd love to have me go out and see what they were doing with bears, but somehow it never took place. "Gee, tell us when you're free." Well guys, all you have to do is tell me when you have things planned, and I'll be there. And it never happened.

So, I thought bison were interesting and we didn't have a whole lot of information about them. I had several ideas in terms of research, but the period (1960s) was very much one of the range management perspective. Bill Barmore [park ranger and biologist from 1962 to 1970] and I were both out of that period. I'd go up Hayden Valley with Bill and with Bob Howe and the Soil Conservation Service people and listen to them make their field evaluations. I give Bill a lot of credit—to be brought here as a range management person, and to be able to look at his own data and say the elk weren't a problem—watching Bill make that transition was very interesting.

Building a Comparative Photo Set

YS: Tell us about how the concept of working with the historic photos started.

MM: Even when I dealt with bison in my doctoral dissertation in the sixties, I was very interested in what has since become known as environmental history. When Doug Houston came to Yellowstone as a research biologist in 1970, he was interested in using comparative photos as a research tool for a sense of time and what changes humans may or may not have caused.

So we started to assemble a comparative photo collection and agreed from the very beginning that we were going to do the retakes ourselves—it was much too much fun. That proved to be the best way—our own presence at the sites helped us a great deal with interpreting the photos and identifying plant species and so forth. Many early photos were labeled only "Yellowstone National Park." Without knowing the park fairly well, we couldn't begin to guess where those photos had been taken. People who create history, whether it's photographic or written, don't do it for people like us. They're doing what interests them at the time, and most photos tend to be people-oriented. A hundred years hence, someone may not care who the people are, or where the building is unless they are into cultural resources, but the background may tell a lot biologically. Many of the early photos were where people went, and part of that's just ease of access. But oh, bless the geologists, because where they were photographing cliffs, we were interested in, say, avalanche paths and the state of the forest below.

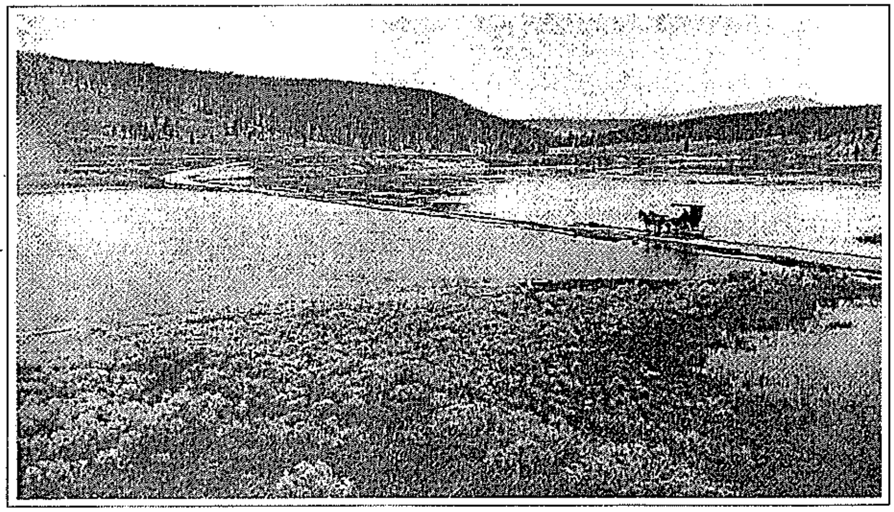
I first started flying with Dave Stradley [pilot and co-owner of Gallatin Flying Service] in 1961; we have probably the longest track record of working as a team in the business. But he had never flown the park then, so we'd take a map along. Now it's much easier; we don't talk much about what we need to do; I just let him sit up front with the Nikon and his skill and sharp eyes.

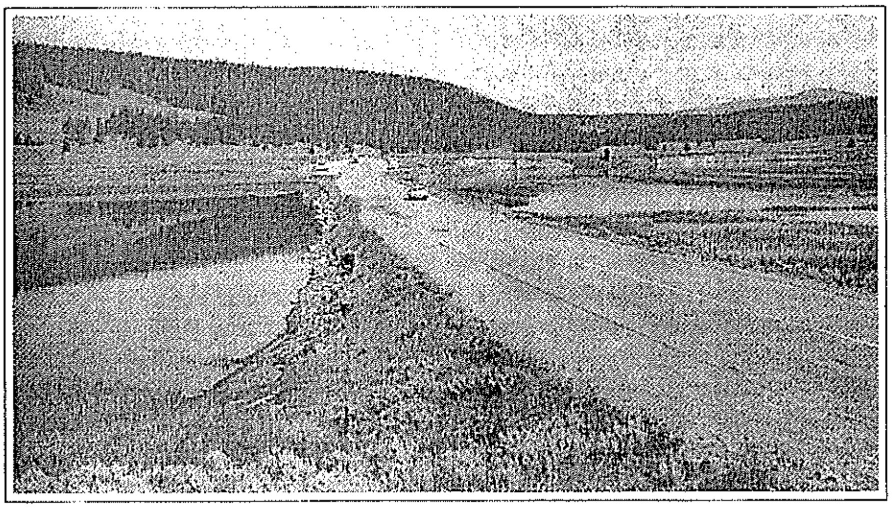
YS: I picture Dave's taping up a photograph in the cockpit of his plane, looking for where these historic photographs were taken. I'd never thought about it as an adventure, but it would be tremendously fun as well as being useful.

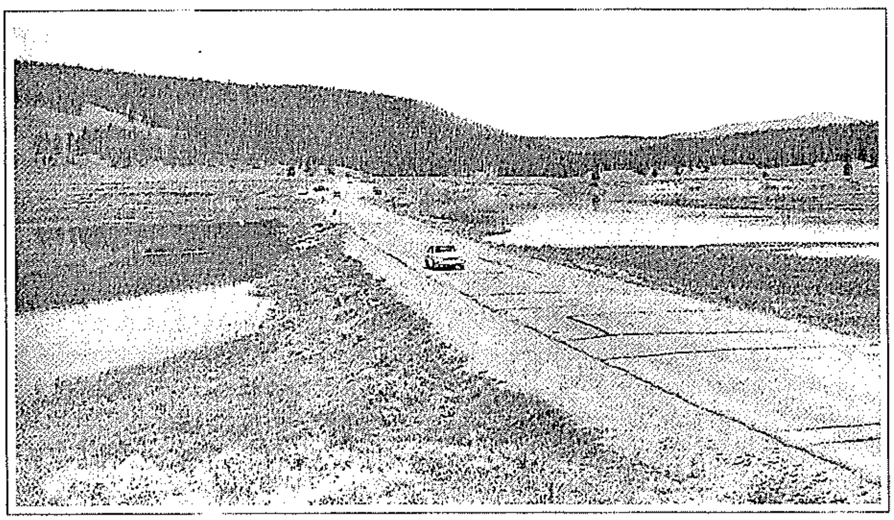
MM: Oh, it was—that's why we never hired anybody. The old cameras had different focal lengths, and I think it took me three trips to Table Mountain to put my feet where that original photo had been taken. I beat all through the whitebark pine trying to get the perspective.

YS: At the time you started taking the photographs, you didn't necessarily anticipate a book 25 years later?

MM: No, we had no thought of a book; the photographs were a research tool. But we had a wonderful time doing it, and Doug used 50 photo sets in his book on the northern Yellowstone elk. In reviewing Doug's work, Sam McNaughton [grassland ecologist from Syracuse University] commented that the photos were much too interesting just to be an appendix. But Doug had transferred to Olympic National Park. We didn't really have a basis for pursuing the idea of a book until the fires of 1988. I will be forever fascinated at watching a natural force like that







One of Meagher and Houston's series of photos. At top is U.S. Army plate 9521, first photographed July 9, 1909 by U.S. Army Engineers. The view is of Alum Creek, a tributary of the Yellowstone River in Hayden Valley, looking north. At center is the first retake on July 27, 1971. The bottom photo was taken July 12, 1991. Between photo 1 and 2, Meagher notes the effects of road construction, influencing riverbank vegetation and sedges, and the forested hill in the background where lodgepole invaded the meadow edges; photo 3 shows the effects of 1988 fires. She also notes that bison were absent in the valley from the 1890s to 1936.

at work. I called Doug every couple of days that summer, and he'd been pacing the floor—talk about a deprived biologist, not to be here! I wanted to rephotograph everything that burned.

YS: Was yours and Doug's the first effort to build a comparative photo set?

MM: Oh, no. This kind of thing has become of great interest in the last 25 to 30 years. One of the first was a very striking effort done in the Black Hills that caught a lot of people's attention. There's a very nice one—*Rangeland Through Time* by Kenneth Johnson—working with [W.H.] Jackson photos in Wyoming. But for Yellowstone there had not been a systematic effort. Having a series of three photos—that is the most unique thing about this effort. I don't know of anyone else who has tried to do three. We were fortunate in having 1988 as a triggering event to do a third set.

Agents of Change: Fire and Climate

YS: You write quite a bit in your new book about agents of change and which ones appear to be most powerful from your long-term perspective of looking at the photos. One thing that I'd forgotten was that, yes, there was fire *before* 1988—some of the old photos had been taken very recently after a fire. It wasn't a 1988 fire scene I was looking at, but an *1888* fire scene. Of course we had fire before!

MM: The Punchbowl, for instance, is one of my favorite sets. It was first photographed by Hillers of the USGS about 1885. Having learned a certain amount about fire, I can look at that photograph and estimate that the background had burned 20 to 25 years before, because most of the trees had fallen. I retook that one in the early 1970s, and then it burned again. As with any history, "what you see is what you have got."

A lot of things were said after 1988 about how some forested areas will come back as meadows. Not if you add a time perspective, because you're still dealing with topoedaphic controls. There are some interesting illustrations of that in the comparative photos. One scene we use looks at the north edge of Hayden Valley from the south edge of Alum Creek. If you look in the background, you'll see an earlier fire and see that the meadow patterns are