Changes in Geomorphic Processes in the Snake River Following Impoundment of Jackson Lake and Potential Changes Due to 1988 Fires in the Watershed

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✦ Objectives

Rivers are dynamic features of the landscape whose characteristics vary over time and space with changes in environmental controls. The Snake River in Grand Teton and Yellowstone National Parks has responded to the impoundment of Jackson Lake and subsequent changes in the operation of Jackson Dam. The 1988 fires in the Snake River watershed may also affect channel morphology. Whether a new system equilibrium might be attained and the extent to which the effects of past events might persist in the fluvial landscape, are two critical questions that need to be addressed for the Snake River. The stability of the Snake River, in turn, will affect the quantity and quality of riparian and aquatic habitats judged to be critical to fish and wildlife in the parks. Stream channel dynamics of the Snake River in Grand Teton National Park are also intimately tied to issues of floodplain delineation and management, the aesthetic value of rivers, and the quality of recreational float trips.

The purpose of this three-year study is to describe, explain and predict changes in the geomorphology of the Snake River (from Jackson Lake Dam to Moose) and related changes in riparian vegetation due to Jackson Lake Dam, and 1988 fires in the watershed. Specific objectives are to determine changes over time and space in:

1. sediment mobilization on hillslopes from rainsplash and overland flow;
2. sediment delivery to streams from slope failures;
3. equilibrium condition and relative stability of the Snake River; and
4. extent of various riparian vegetation communities in the Snake River floodplain.

✦ Methods

The first objective was achieved through a series of rainfall simulation experiments. The methods employed in collecting and analyzing these data were described in the *1989 UW-NPS Annual Report* (Marston et al. 1989). Sites for the experiments were chosen to reflect differences in logging and fire history on the two dominant geologic substrates (Table 1).

Table 1. Plot distribution for rainfall simulation experiments.

History of Logging and Fires	Number of Plots Glacial Till	Volcanic
Logged before 1988 fires and burned	8	12
Unlogged before 1988 fires and burned	20	12
Burned and logged after 1988 fires	0	4
Unlogged and unburned by 1988 fires	4	0

Progress toward achieving the second objective has been made through 1989 field surveys of slope failure mapped by the Wyoming Geological Survey. Slope failures were grouped into two types:

1. rapid-shallow failures: including dry debris avalanches and wet debris flows; and

2. slow-deep failures: including blockslides (especially slumps), earthflows, and debris flows.

The data collected in the field surveys of slope failures were described in the *1989 UW-NPS Annual Report* (Marston et al. 1989). The timing of past slope failures was estimated in selected cases using dendrochronology. Each slope failure surveyed in the field was evaluated for potential sediment delivery to stream channels using procedures developed for the U.S. Environmental Protection Agency and U.S. Forest Service by Swanston and Swanson (1980). Work in the third year of the project (1991-92) will estimate total sediment delivery to channels from slope failures, by coupling the USFS-EPA procedures with data on controlling variables, in a geographic information system (GIS) of the watershed.

The third objective was achieved through analysis of aerial photography and topographic maps combined with field surveys of the 42-km section of the Snake River from Jackson Lake Dam to Moose Junction. Procedures for mapping the channel and for conducting the stream surveys were described in the *1989 UW-NPS Annual Report* (Marston et al. 1989). The 100-year floodplain was transferred from 1989 Federal Insurance Management Agency maps to our maps, and the width of the floodplain was measured. The stream survey data were entered into a computer data base for statistical analysis. Based on spatial trends in the stream surveys data and inspection of the channel maps, the 42 km long study section of the Snake River was divided into five distinct reaches. A measurement of "total sinuosity" was made of each of five reaches along the Snake River. Sinuosity is defined by Richards (1982) as the total channel length (including all braids) divided by the distance through the channel belt along straight segments which either connect the inflection points of meanders or are oriented midway through a belt of braided channels. The assessment of equilibrium condition for each reach was based on the degree to which channel pattern changed over time. Relative channel stability was described for each reach using criteria developed by Schumm (1981), supplemented by evidence provided by the stream survey data.

Progress toward achieving the fourth objective was made during the summer of 1990 by conducting field surveys of riprain vegetation. Preliminary maps of riparian communities were prepared from 1975 orthophotos and 1987 color aerial photos. Mapping units were delineated on the basis of plant height and density, shadows, shape of the crown margin, foliage pattern, texture, and color. Trees, shrubs, and ground cover (soil texture, percent grass and detritus) were measured along two 100-meter long transects at each of 60 sites. Trees were sampled with the point-quarter method; shrubs and ground cover were sampled with the line intercept method, following procedures outlined by Mueller-Dombois and Ellenberg (1974). The sites were chosen from the preliminary vegetation map to provide a data set with an equal number of vegetation units in each of the five reaches. Consideration was also given to access from either roads or from the river. A final vegetation map will be produced from interpretation of 1989 color aerial photos using mapping criteria for the communities classified from field survey data. Community diversity will quantified in terms of "relative richness" and "relative evenness" following the guidelines presented by Romme (1982).

✦ Results

The second year of this three-year project has offered several insights regarding the four project objectives.

The results of the rainfall simulation experiments on runoff and soil loss are summarized in Tables 2-3. The rates of runoff reached a maximum of 96 percent of the applied rainfall on a plot with water repellant soils and no litter. The rates of runoff were generally higher on volcanic soils than on glacial till (Table 2), but the difference was not statistically significant at $p < 0.001$ (Mann-Whitney test). The differences between plots with contrasting histories of logging and fires were also not statistically significant at $p < 0.001$ (Kruskal-Wallis test). The differences in runoff stratified by both geology and logging/fire history were not statistically significant at $p < 0.001$ (Kruskal-Wallis test). The data were also analyzed using stepwise multiple regression. The resulting equation, with independent variables listed in the order they entered the equation, was:

Table 2. Runoff for rainfall simulation experiments.

History of Logging and Fires	Mean Runoff (liters) Glacial Till	Volcanic
Logged before 1988 fires and burned	16.2	21.1
Unlogged before 1988 fires and burned	18.7	22.1
Burned and logged after 1988 fires	——	19.7
Unlogged and unburned by 1988 fires	15.7	——

$$\text{Log } R = 2.11 - .042 (\text{Log } L) - .610 (\text{Log } S) - .063 (\text{Log } W) + .260 (\text{Log } H1) + .233 (\text{Log } H2) + .194 (\text{Log } H3)$$

where

R = runoff for the 1-hour storm (liters)
L = litter cover (percent)
S = silt content of soil (percent)
W = minimum depth of wetting (millimeters)
H1 = dummy variable for logging/fire history (1 if unlogged; 0 if logged)
H2 = dummy variable for logging/fire history (1 if logged before 1988 fires; 0 if not logged before 1988 fires)
H3 = dummy variable for logging/fire history (1 if logged after 1988 fires; 0 if not logged after 1988 fires)

This regression was significant at the $p < 0.001$ level, with a cumulative r^2 of 0.38.

Table 3. Soil loss for rainfall simulation experiments.

History of Logging and Fires	Mean Soil Loss (grams) Glacial Till	Volcanic
Logged before 1988 fires andburned	562.2	511.8
Unlogged before 1988 fires andburned	300.4	422.3
Burned and logged after 1988 fires	——	393.1
Unlogged and unburned by 1988 fires	8.5	——

The rates of soil loss reached a maximum of 2.5 $kg/m^2/h$. The rates of soil loss were not statistically significant between volcanic and glacial terrain at $p < 0.001$ (Mann-Whitney test). The differences between plots with contrasting histories of logging and fires were statistically significant at $p < 0.001$ (Kruskal-Wallis test). The rates of soil loss were highest at sites which had been logged and subsequently burned by the 1988 fires. This can be attributed to the higher fuel loads which would have existed on the forest floor, leading to more intense burns. The differences in runoff stratified by both geology and logging/fire history were statistically significant at $p < 0.001$ (Kruskal-Wallis test). The data were also analyzed using stepwise multiple regression. The resulting equation, with independent variables listed in the order they entered the equation, was:

$$\text{Log } E = .129 - .162 (\text{Log } L) + 1.52 (\text{Log } H1) - 1.32 (\text{Log } H2) + 1.61 (\text{Log } H3) + .679 (\text{Log } S)$$

where

E = soil loss for the 1-hour storm (grams)
L, H1, H2, H3, S as above

This regression was significant at the $p < 0.001$ level, with a cumulative r^2 of 0.85. Litter density was the key variable controlling both runoff and soil loss. The timber harvest methods contribute to the degree to which litter will suppress soil loss after the fires. Lodgepole forests are typically clearcut which leaves no source of post-fire needlefall to replenish litter cover. Even in lodgepole forests which were not logged before the 1988 fires needles were easily burned. Douglas-fir forests which were selectively logged prior to the fires provided post-fire needlefall because the needles are more fire-resistent.

It would seem that the active role of logging/fire history on soil loss must be reconciled with the passive role of logging/fire history on runoff. The two results were not inconsistent, because the majority of soil was mobilized by rainsplash, not by runoff. This interpretation was supported by the relative lack of soil loss associated with snowmelt runoff, while soil loss from summer thunderstorms was quite pronounced. Regression analyses revealed that silty soils caused lower runoff but higher soil loss, further accounting for the poor correlation between runoff and soil loss.

The potential for sediment delivery to streams from slope failures depended on the type of failure analyzed. The potential sediment delivery from rapid-shallow slope failures averaged 50 percent of the total volume of the failures and was a function of slope gradient and slope irregularity. The potential sediment delivery from slow-deep slope failures averaged 95 percent of the total volume and was a function of slope position. The total potential sediment delivery from the rapid-shallow and slow-deep slope failures surveyed was estimated to be 2.4×10^6 cubic meters and 34.4×10^9 cubic meters, respectively. A complex slope failure on Gravel Creek accounted for 96.7 percent of the total volume surveyed. Of the total of 62 slope failures surveyed, 43 were situated in unburned areas and 19 in burned areas. Ten of the 19 in burned areas have an increased potential for sediment delivery to stream channels as a result of the fires. However, no direct evidence was uncovered in the upper Snake River drainage of accelerated slope movement related to the 1988 fires, in contrast to reports elsewhere in the Greater Yellowstone Area. Dendrochronology was performed on a total of 32 trees cored on five different slope failures. The data revealed sporadic movement beginning in 1890, 1935, 1958, and 1967. These dates, however, do not preclude earlier movement. In general, the larger slope failures which existed prior to the 1988 fires have been little affected by the fires because:

1. they are large and deep-seated, with a sliding plane below the extent of tree roots;
2. the more open terrain on unstable slopes supports fewer trees for burning and the typical hummocky topography retains moisture;
3. low-fuel producing aspen dominates unstable terrain instead of the more flammable conifers; and
4. broken topography tends to act as a firebreak.

The 42 km long study section of the Snake River was divided into five reaches:

1. Jackson Lake Dam to Pacific Creek (0-7 km): single channel, pools, narrow floodplain, low gradient, substrate of fines;
2. Pacific Creek to Sagebrush Island (7-13.5 km): compound channel, glides/riffles, not as deep as reach 1, substrate more coarse than reach 1, steeper gradient;
3. Sagebrush island to Deadman's Bar (13.5-24 km): larger substrate than reach 2, large floodplain width;
4. Deadman's Bar to Frustration Ponds (24-30 km): entrenched meandering channel, more rapids than other reaches, increase in channel gradient and substrate sizes;
5. Frustration Ponds to Moose (30-42 km): compound channel, fewer rapids than reach 4 but steeper gradient and wider floodplain.

The reaches also exhibited differences in terms of total sinuosity and variability over time in sinuosity (Figure 1). The highest values of total sinuosity and the greatest variability over time in total sinuosity was observed in reaches 2, 3, and 5. These reaches have wide floodplains, high gradient, and abundant supplies of sediment from either tributaries or erosional cutbanks. Reach 1 has a narrow floodplain and low gradient; reach 4 has a steep gradient but is entrenched and is therefore able to transport the imposed sediment load. The temporal trends in total sinuosity were

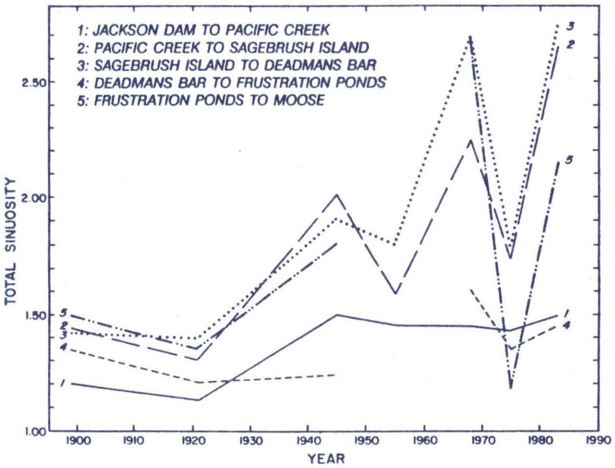

Figure 1. Total sinuosity for each of the five reaches of the Snake River between Jackson Lake Dam and Moose, Wyoming.

related to the frequency of peak flows released from Jackson Lake Dam. Total sinuosity increased in periods when overbank flows were significant either in terms of frequency (1899-1945) or magnitude (1975-1983). In these periods, new channels were opened which increased total sinuosity through increased braiding. Total sinuosity increased from 1955-1968 even though peak flows were at a minimum. This has been attributed to the accumulation of sediment from tributaries during this period. Total sinuosity decreased in periods of few peak flows (1945-1955, 1968-1975) when overflow channels would be abandoned and reattached to the floodplain or mid-channel islands.

The effects of Jackson Lake Dam on equilibrium conditions in the Snake River has been revealed by

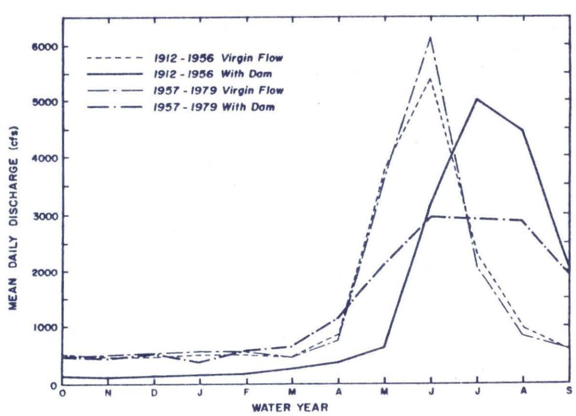

Figure 2. Actual hydrographs (bold lines) and virgin flow (i.e., without Jackson Lake Dam) for the Snake River near Moran for periods before and after Palisades Reservoir was completed (1957)

compiling a series of hydrographs for the Snake River gage near Moran, based on periods before and after the completion of Palisades Reservoir near the Idaho-Wyoming border (Figure 2). Between 1912-1956, Jackson Lake Dam had little effect on the magnitude of peak flows, but did cause a one-month delay in the peak. Following the closure of Palisades Reservoir, the release schedule was altered for Jackson Lake Dam. The magnitude of peak flows was decreased which eliminated the hydrologic events which were destructive to riparian vegetation. This was coupled with an increase in late summer flows, raising the water table which in turn facilitates vegetation encroachment on channel deposits. Virgin flows in the two periods were quite similar, indicating that climate change has not been a driving force in the fluvial system of the Snake River.

Five riparian communities have been tentatively identified:

1. unvegetated channel deposits (mid-channel bars, point bars);
2. shrub-swamp community dominated by willow and mountain alder;
3. open (low tree density) forest dominated by cottonwood;
4. mixed forest (moderate tree density) of blue spruce and cottonwood;
5. closed forest (high tree density) dominated by blue spruce.

The mapping of these communities and measurement of community diversity are in-progress and will be completed in FY91.

✦ Conclusions

The 1988 fires in the Snake River watershed have increased sediment mobilization on hillslopes due to rainsplash and overland flow. The reestablishment of ground cover and surface litter will suppress sediment movement by these processes. Sediment stored behind fallen logs could be remobilized upon salvage logging. The 1988 fires will have little affect on slow-deep types of slope failures, but are expected to accelerate rapid-shallow forms. The sediment supplied to streams from rainsplash and overland flow will be too small to cause persistent changes in channel morphology, although some sediment storage can be expected in willow-covered floodplains. However, slope failures will introduce larger particles to the

Snake River and its tributaries with more persistent impacts.

The closure of Palisades Reservoir initiated changes in the reservoir release schedule of Jackson Lake Dam, with consequences to channel morphology. Without peak flows to cut new channels and move sediment, the braided sections of the Snake River revert to a compound pattern and eventually to single meandering channels. This trend is preferred by those who prefer to see the Snake River managed for recreational float trips. However, channel stability may be obtained at the expense of riparian community diversity.

✦ Literature Cited

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