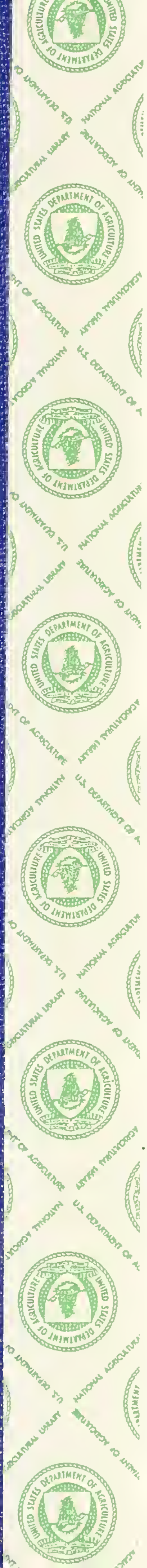

United States
Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

Research Note
PNW-382
April 1981

Use of Pre-Fabricated Parshall Flumes to Measure Streamflow in Permafrost-Dominated Watersheds

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Abstract

The occurrence of permafrost in stream valleys of central Alaska causes problems with conventional stream-gauging installations. To minimize both thermal and physical disturbance at measurement sites, pre-fabricated Parshall flumes have been used to monitor streamflow at sites underlain with permafrost in a subarctic research watershed. Flumes ranging in capacity from 263 to 700 liters per second (l/s) were installed and have performed satisfactorily for two open-water runoff seasons.

Keywords: Stream gaging, streamflow, permafrost, subarctic environment, Alaska (central).

Problem

In permafrost[1] -dominated valleys such as those in the taiga of central (subarctic) Alaska, routine measurement of stream discharge poses problems not encountered in more temperate settings. Central Alaska lies in the zone of discontinuous permafrost. In this zone, permafrost is found on north-aspect slopes, in topographically sheltered valleys, and in low-lying, poorly drained settings. Slopes facing directly south (south aspect) are normally free of permafrost. Latitude is strongly expressed in the distribution of frozen ground; as one moves north, the relative proportion of permafrost increases until, on Alaska's "North Slope" (the northern side of the Brooks Range and the Arctic Coastal Plain) permafrost is virtually continuous.

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[1] In conventional usage, permafrost is considered as any earth material (soil, bedrock, or soil/ice matrix) whose temperature remains below 0°C for at least 3 consecutive years.

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In subarctic Alaska most of the headwaters and upland streams (first, second, and third order) occupy valleys partially or wholly underlain by permafrost. This frozen ground is relatively warm (−0.5° to −1.5°C), and thus sensitive to minor changes in energy balance at the soil surface. This thermal sensitivity has been widely discussed and documented, most commonly in terms of the environmental impact of resource development activities (National Academy of Sciences—National Research Council 1973, Gold and Lachenbruch 1973, McVee 1973, Brown 1973, Bureau of Land Management 1977).

Change in thermal regimen can consist of lowering or raising the mean annual temperature or altering the diurnal or seasonal energy flux. The most common change is raising the temperature of frozen soil, usually the result of changing the surface albedo, the thermal conductivity of surficial materials, or both. With "warm" permafrost, only small changes in heat input will raise soil temperatures above freezing. If the soil is coarse-textured, well drained, or has low moisture content, temperature increase and soil thaw may have little or no effect on the physical stability of the soil. Similarly, frozen bedrock will normally be physically stable even if thawed. If, however, the soil is fine-textured (silt or silt loam) and has high moisture content, it may be extremely unstable when thawed. Much of central Alaska's landscape includes soils developed in fine-grained aeolian silts. Moreover, in many cases frozen water constitutes up to 50 percent or more by volume of the soil mantle. In such soils the potential for movement or slope failure with thawing is obvious and well-documented.

The relationship of frozen ground to streamflow measurement is less direct. Continuous streamflow measurement is conventionally accomplished at stream sections artifically controlled with weirs or flumes. These regulate stream stage (water depth) in a confined cross section. Such installations commonly have both side and bottom "cut-off walls" extending well into stream banks and bed. These are designed to force water that may be moving in the soil adjacent to or beneath the stream channel into the measurement section (Bureau of Reclamation 1975). Many installations also incorporate ponds upstream from the control section to reduce turbulence and provide uniform flow conditions through the control reach. Construction of cut-off walls in a stream bank composed of ice-rich silt can result in increased heat input to the bank, from decreased surface albedo and insulation resulting from construction, and from the higher thermal conductivity of material used in the cutoff walls. During the open-water season (generally May through mid-October in this area), ponds formed upstream from an artificial control can constitute major sources of heat which is transferred to adjacent stream banks and to sub-channel materials. Since the temperature of water is above 0°C, and permafrost is below 0°C, the inevitable result of ponding water in frozen terrain is heat transfer to the soil, and subsequent soil thaw.

This sequence was documented in the first study of upland hydrology in central Alaska, at Glenn Creek near Fairbanks. Dingman (1966) installed a steel, vee-notch weir in the channel of a first-order stream draining a 181-hectare catchment. The channel was developed in deep (10-m) Fairbanks Silt Loam, frozen from 0.5 m to bedrock. Within 3 years of installation, the soil adjacent to the steel wing-walls had thawed, as had soil beneath the stilling pond upstream of the weir blade. Leakage beneath and around both ends of the weir was substantial. Despite efforts to insulate and grout the installation, soil thaw and physical erosion continued at an increasing rate until termination of the project in 1968 (Dingman 1971).

The U. S. Geological Survey has responsibility for the largest number of stream-gaging stations in Alaska, (Geological Survey 1978); they have approached the measurement problem in permafrost by avoiding structures. USGS installations in interior Alaska are normally "natural control" sections, commonly a pool-and-riffle sequence with stable outlet conditions. Stage recorders monitor water level in the natural pool (which is presumably in thermal and physical equilibrium with channel and banks); and repeated manual measurements of discharge are used in the construction of a stage-discharge relationship (rating curve) unique to each site. This approach has both advantages and disadvantages. Avoiding in-stream structures precludes some, but not all, of the problems encountered in permafrost terrain and eliminates the cost of installing and maintaining artificial controls. On the other hand, repeated manual measurements are needed at various stream stages to establish (and subsequently verify or correct) the rating curve for each site. The natural channel may experience changes in hydraulic characteristics, particularly during and following extreme hydrologic events, and measurement accuracy is likely to be very low in small, upland streams, particularly at low stages.

Approach

In an attempt to improve acquisition of streamflow data in the Caribou-Poker Creeks Research Watershed (Slaughter and Lotspeich 1977), 45 km north of Fairbanks, Alaska, we installed prefabricated, fiberglass Parshall flumes (Bureau of Reclamation 1975), manufactured by Warminster Fiberglass Company, Warminster, Pennsylvania. Advantages foreseen for these installations included standardized cross-sections allowing greater measurement accuracy than natural channels (particularly at low flows), minimal physical modification of the natural stream channel, minimized alteration of the thermal regimen of the measurement site, and simple, rapid field installation.

Three prefabricated flumes have been installed to date. The first had a 9-inch (23-cm) throat, with rated flow capacity of 9.3 ft^3/s (263 liters/s).[2] It was installed in late August 1977 in the channel of subdrainage C-2 (fig. 1), which has a drainage area of approximately 5.2 km^2. Soils in the valley adjacent to the stream are Karshner Silt Loam, described as ". . . poorly drained, stratified silty and very gravelly sandy soils with shallow permafrost. These soils are formed in narrow flood plains bordering the upper courses of streams" (Rieger et al., 1972). The slight modification of the natural channel required consisted of shaping the channel floor to conform to flume geometry, and cutting less than 20 cm into the bank to allow for a side-mounted stilling well. The intake reach was lined with plywood for 4.8 m upstream, to supply uniform inflow conditions. Void space between flume walls and natural channel banks was filled with urethane foam mixed on the site. This provided insulation between flume and banks, minimizing possible thermal degradation of the banks.

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[2] Actual maximum flow capacity, at 2.5 ft head, is 12.47 ft^3/s (353 liters/s).

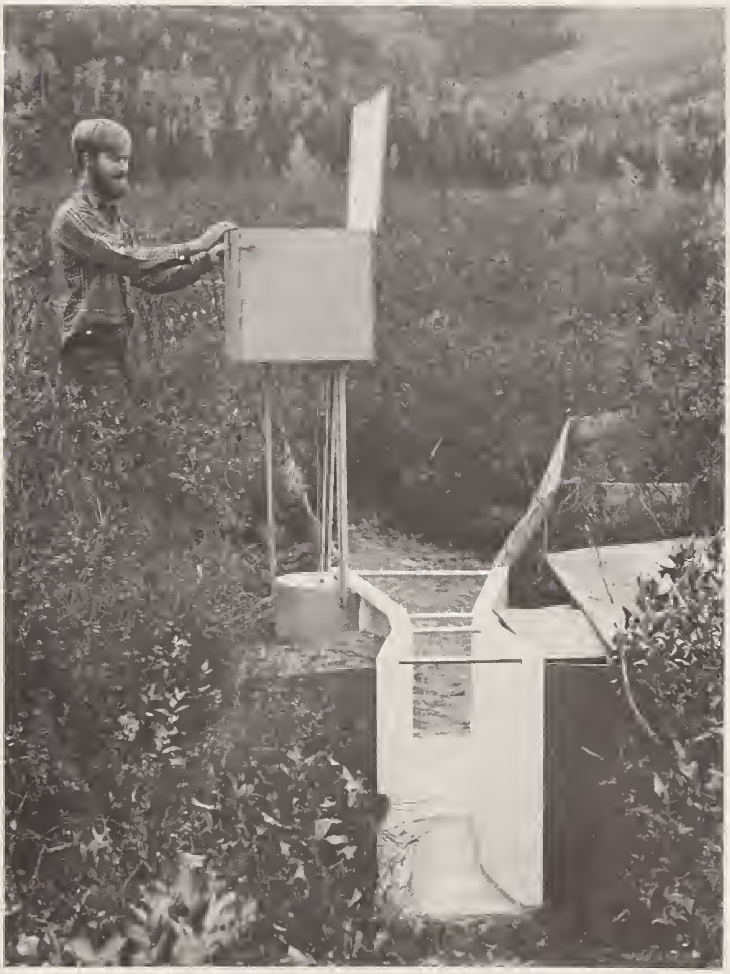

Figure 1.—Parshall flume in C-2 channel; view is upstream. Water-level recorder is in box above the stilling well.

This installation was used during the last weeks of the 1977 runoff season and during the 1978 and 1979 open-water seasons. Of particular interest was its stability during spring "breakup", when in most seasons there are large amounts of ice in and adjacent to the channel. In both 1978 and 1979, ice in the channel and flume remained until after the greater part of the snowpack had melted (fig. 2). Consequently, snowmelt runoff was not measured, however, the flume itself remained stationary and level through both winters.

Following successful measurement of summer flow at the C-2 site installation, and its survival of spring breakup, a second 9-inch-throat fiberglass Parshall flume was installed in subdrainage C-3 (drainage area, 5.5-km^2). This is also a first-order stream, with a catchment dominated by permafrost as result of its

Figure 2.—Parshall flume in C-2 channel; ice surrounds flume in late April. Clock was added for time-lapse photography at the site.

dominant north-northeasterly aspect. Valley soils are Karshner Silt Loam (Rieger et al. 1972). The channel reach chosen was not as attractive in terms of hydraulic characteristics as the C-2 site. Because the channel was wider, more extensive intake walls had to be constructed on the left bank. This installation (fig. 3) was completed in July 1978 and was stable through the remainder of the 1978 runoff season and throughout the spring 1979 breakup and subsequent summer.

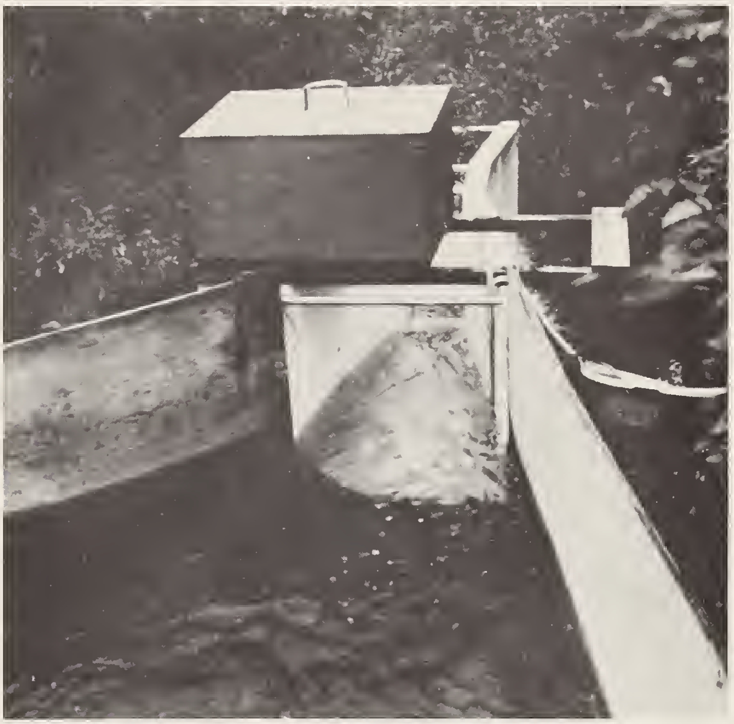

Figure 3.—Parshall flume in C-3 channel, second season after installation. Water-level recorder is in box over stilling well; view is downstream.

For stage recording, the C-2 flume was equipped with a Fisher & Porter digital water-level recorder, while the C-3 site utilized a Leupold-Stevens Type F water-level recorder. Both recorders utilized floats in stilling wells attached directly to the fiberglass flumes. Both installations are considered successful in terms of providing conditions for more accurate flow measurement and allowing reliable recording of water stage and discharge throughout the open-water season.

The problem of ice choking the flumes during spring snowmelt has not been satisfactorily resolved. Both streams continue to flow throughout the winter, but at levels of less than 30 liters/s. With continued flow when the stream channel is completely frozen over, aufeis ("overflow" or "nalyd") is a continuing problem. Ice formed when base flow comes to the surface as result of constriction or blocking of normal flow routes by freezing can fill the channel and extend over an entire floodplain (Carey 1970).

In both the C-2 and C-3 valleys, aufeis has been a recurrent phenomenon. During spring 1979, we attempted to open both the C-2 and C-3 channels at the flume prior to breakup to allow measurement of spring snowmelt runoff. We tried physically sawing out the ice, which was up to a meter thick, with chain saws and removing it from the channel and flume but were unsuccessful. Continued base flow re-filled the channel and flume with ice at both sites within a few days after cleaning. We did observe that the excavated sections were the first to melt out during spring runoff. This suggests that ice removal, followed by continued direct maintenance of the channel, with repeated ice removal if necessary, might allow direct measurement of spring snowmelt runoff at these locations.

A larger flume was installed in late fall 1979 in the subdrainage C-4 of the Caribou-Poker Creeks Research Watershed. This flume has an 18-inch (45.7-cm) throat with a rated capacity of 24.7 ft.^{3}/s (700 liters/s).[3] Although this unit has not yet been subjected to a complete runoff season, we expect it to be as stable and successful as the first two installations.

It should be noted that another, virtually identical Parshall flume has been installed since our initial work. In an attempt to reactivate measurements of Glenn Creek runoff at Fox, Alaska, Bredthauer[4] (personal communication) followed our procedures in summer 1978 when he installed a 9-inch-throat (23-cm) Parshall flume at a point several hundred meters from an earlier steel weir installation. This installation was apparently stable through the 1979 runoff season.

Summary

Faced with problems of thermal and physical bank degradation in installations utilizing weirs and pools, we installed prefabricated fiberglass Parshall flumes for streamflow measurement in first-order streams in permafrost-dominated central Alaska. Experience during two runoff seasons indicates that the flume installations have provided a relatively inexpensive, accurate, and low-site-impact method of continuous runoff monitoring. Critical to this success was the care taken to minimize physical and thermal disturbance to both banks and channels at installation sites.

Acknowledgments

Austin Helmers (USDA Forest Service, retired) and Eugene Culp (Hydrologic Technician, Institute of Northern Forestry) provided valuable cooperation and assistance with design and field installations described in this note.

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[3] Actual maximum flow capacity, at 3.0 ft-head, is 41.24 ft^3/s (1 168 l/s).

[4] Personal communication from S. Bredthauer, Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska.

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GPO 992-898