that should be given serious and careful consideration. Experience in machine techniques is an absolute requirement for judging the feasibility of automatic computation by digital computers. After the feasibility is determined, the next step - that of actual programming the problem in computer language - is a job for a specialist. Ideally, the engineer should be sufficiently familiar with machine requirements and procedures to understand thoroughly the use of the various operation codes and data processing techniques. He may, however, delegate the task of coding to a specialist. Actually, a trained and experienced programmer represents a most important link in the successful and efficient application of digital computers to technical problems.

The procedure described by Mr. Ellis is of particular interest to engineers of the Corps of Engineers. The application of the Datatron Computer system power studies is similar in many respects to the program developed for analyzing the Columbia River Power System. In connection with the review of House Document 531, the Columbia River Review Report, the studies of power capabilities of the Columbia River system were made by personnel of the North Pacific Division office, U. S. Corps of Engineers, on the IBM 650 Electronic digital computer. The use of this program was begun in June 1956. The scope of the studies involved the analysis of system power capabilities for several levels of development to be expected in the payout period of major federal reservoirs. The systems analyzed involved as many as 60 hydroelectric projects.

In general, the details of machine operation for Mr. Ellis' program basically follows a method for evaluating hydroelectric capability. The principal factors are streamflow, release of water from reservoir storage, gross head, and the plant characteristics including efficiency and hydro-capacities. The use of algebraic equations to express the physical relationships between storage, head, and power are both linear and quadratic, non-linear relationships may also be evaluated on computers by an operation known as "table-look-up." By use of this code, the machine has access to stored values of a relationship on the memory drum (as, for example, a stage-discharge rating curve) and thereby provides a fast and convenient solution to a curvilinear relationship.

Mr. Ellis is to be congratulated on an interesting and timely paper.

WINTER SNOW OBSERVATION ON MT. OLYMPUS

By

E. LaChapelle[1]

The Blue Glacier Project, under the Department of Meteorology and Climatology, University of Washington, is part of the United States International Geophysical Year program for glaciological studies in the Northern Hemisphere. This program is a complement to the U. S. Antarctic glaciology program, and will provide new information on the nature, location, present state, past history, and dynamics of existing glacierization in arctic, sub-arctic and temperate North America. The Blue Glacier, located on the northern flanks of Mt. Olympus in the Olympic peninsula of Washington State, has been selected for a year-around study of typical, active temperate-zone glacier in a maritime climate.

The purpose of the Blue Glacier Project is to examine the mass and energy exchange between such a termally temperate glacier and its environment. The mass exchange is represented by deposit of snow in the winter and the runoff of melted snow and ice in summer. In such areas of heavy snowfall as the Olympic Mountains, this annual mass exchange is large, and measurement of the heavy winter accumulation requires daily records from the glacier throughout the winter months. The principal energy exchange between the glacier and such an environment is the heat supply required to melt the snow and ice in summer, and is relatively insignificant in the winter. The program of observations is designed to measure glaciological features on a year-around basis, with emphasis on the micrometeorology of a melting snow surface. A valuable by-product is the

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collection for the first time of quantitative climatological data from a high altitude in the center of the Olympic Mountains, an area which has long been thought to experience the heaviest annual precipitation in the continental United States.

The Blue Glacier is sustained by two heavy accumulation areas on the northern slopes of Mt. Olympus; a cirque and a snow plateau whose altitudes range from 6500 ft. to 7600 ft. Ice drainage from these two sources plunges northward in separate steep icefalls to coalesce at about 5600 ft. elevation, forming a single valley tongue of moderate gradient which terminates at 4300 ft. From the head of the cirque to its terminus, the Blue Glacier is 2.5 miles long, with a maximum width of 0.7 miles at the base of the icefalls. Seismic and borehole explorations of the lower glacier by a California Institute of Technology team have revealed maximum ice depths of about 900 ft. in the area just below the developed firn limit, which lies at about 5500 ft.

The principal observation site for weather, micrometeorological and glaciological studies is at 6800 ft. on a nearly level area of the snow plateau, where a small frame building houses instrumentation and recorders. Living quarters for the field personnel are in a frame building on bedrock immediately to the north of the plateau, with an adjacent diesel power plant to provide power for the station building and instruments. This site on bedrock is the location of standard climatological observations, including a continuous record of wind and temperature. Daily precipitation records are obtained at both the station site and the instrument location on the snow plateau. Daily records of radiation over the snow surface are obtained for incoming and reflected solar radiation, total incoming radiation, and net radiation balance of the snow surface. During the winter, subsurface temperatures are measured to a depth of 15 meters below the 1957 firn surface, and throughout the winter snow cover. A continuous record of snow settlement is being obtained, as well as general data on snow cover evolution by the periodic excavation of pits down to the summer firn surface. Detailed micrometeorological studies include measurement of wind and air temperature distribution above the snow surface, surface ablation and ice melt, and heat flow in the surface snow layers. Extensive measurements of accumulation and ablation over the glacier surface are used to determine the mass budget. Numerous special investigations, such as measuring the spatial and temporal variations in snow albedo, are also in progress.

At the time this paper is being prepared, the field work of the Blue Glacier Project is approximately half completed. Although data reduction and analysis will require considerable time after the conclusion of field work before the final results can be reported, it is possible at the present to summarize a few interesting results of the winter observations to date, particularly in regard to the climatic conditions of the high Olympics.

Studies are being carried out of the development of winter chill, or winter "cold wave", in the surface firn layers of the accumulation zone. Maximum penetration of sub-freezing temperatures in the firn by mid-February was slightly over three meters, substantiating the prediction that cold wave development would be weak in this climate. Relatively mild temperatures—the winter monthly means have ranged from 24.2° to 29.1° F.—combined with occasional winter rainfalls and the insulation of a deep snow cover, have inhibited freezing of the firn beyond depths which are shallow compared to the thickness of the annual accumulation. It is thus shown that firnification in the Blue Glacier is probably confined to compaction and pressure metamorphism after the firn becomes more than a year or two old, as it then passes beyond reach of the annual refreezing of percolated meltwater.

The climatological record has provided for the first time quantitative data concerning snow, precipitation and temperature conditions in the high Olympics, and confirmed the expectation that this is the wettest area in the continental United States. Table 1 gives a month-by-month summary of the climatological record at the Blue Glacier station from August 1957 through February 1958. The total precipitation for this period of 125.82 inches of water considerably exceeds the valuesrecorded during this same period in the lowlands of the Olympic Peninsula and the western slopes of the Cascade Mountains, where the heaviest precipitation in the United States is usually observed. These heavy precipitation figures are compared in Table 2, where the 1931-1955 average precipitation values are also given, indicating that rain and snowfall have been near normal during this period in Western Washington. Since December 1st the precipitation on the Blue Glacier has maintained a sustained average of 0.98 inches of water per day, almost all in the form of snow. The result is large snowfall figure of 417 inches to the end of February, with a maximum of 207 inches on the ground at that time. The question can be raised why this amount of precipitation does not give an even greater total snowfall. The reduced snowfall figure results from the unusually consistent high density of the freshly deposited snow, which appears to be a definite climatological characteristic of the area. Observed new snow density values range from 0.15 to 0.30 g/cc, with the commonest values around 0.20 to 0.25. The monthly means are given in Table 1. This high new snow density is of considerable significance to the snow cover development and the glacier economy. Such a dense, heavy snow readily compacts into a hard and homogeneous snow cover, which is able to resist deflation by the high winds common over the Olympics in winter. Snowfalls of lower density, as are found in most mountainous areas in winter, would unquestionably be extensively redistributed by the wind to alter greatly the picture of glacierization in the Olympics. The new snow densities are in part attributed to relatively warm temperatures and the effects of wind compaction, but the persistence of dense snowfalls even when these factors are not present points to the existence of other factors as well. From observations to date at least one of these appears to be the strong predominance of needle crystals (Type 4, International Snow Classification Types of Solid Precipitation) in many snowfalls, a crystal type which by reason of its geometry can produce deposited snow of high density.

Sleet and freezing rain have been encountered during each of the winter months so far, producing very heavy icing or glaze, and a hard ice crust on the snow surface. Heavy fogs and riming are also very common, often in conjunction with snowfalls. Above an elevation of about 7000 ft. the peaks are festooned with very heavy accretions of ice, rime, and rime-cemented snow, so very little exposed rock is visible even on vertical cliff faces. These heavy deposits undoubtedly make some contribution to the winter accumulation on the glacier, but the magnitude of this contribution has not been established.

Through the end of February the Pacific Northwest has experienced a relatively warm winter, with mean temperatures above normal. The mean monthly temperatures given in Table 1, particularly those for January and February, are thus probably somewhat higher than normal for the Mt. Olympus area, but, even so, it appears that winter temperatures at the station elevation of 6800 ft. must often be mild. At present very little snow is found throughout the Olympic Mountains below 4500 ft. as a result of warm air and rain at lower elevations. The snow depth increases rapidly above 4500 ft., with the substantial snow cover recorded at the Blue Glacier observation site probably representative of a normal snow year in spite of the abnormally thin snow cover at lower elevations. Seasons such as this can easily deceive a lowland observer about the status of glacier economies, for the accumulation zones of the glaciers are high enough to receive almost all the precipitation in the form of snow while rain predominates at the intermediate elevations where snow is usually experienced in colder winters. In the case of the Blue Glacier even the heavy snow cover on the snow plateau is not truly indicative of the winter accumulation. This site is fully exposed to sweep of storm winds from the Pacific, and is not the maximum accumulation zone of the glacier. The high cirque at elevations of 7000 ft. to 7600 ft. has received this winter an accumulation of snow which may approach twice that at the plateau station. In addition to being higher, it forms a natural catchment basin to the lee of southwest storm winds, and efforts to measure accumulation here have been frustrated by snowfall so heavy that marker poles 6 to 8 ft. above the snow surface have been covered in a single storm period. In one ten-day period in December two of three stakes extending 10 to 14 ft. above the snow were completely buried, and only a foot was left exposed of the third. The present winter snow depth in this cirque is estimated at 30 ft. or greater.

In conclusion it may be said that winter snow observations to date amply confirm the important role of extremely heavy winter snowfall in sustaining active glacierization at the lowest elevations in the continental United States. Under the present climate there is little question but that the Blue Glacier is dynamically an active glacier, and not just a stagnant ice remnant of a colder period which is now barely clinging to existence, as is the case of many glaciers in the United States. If all the Blue Glacier were removed today from the northern slopes of Mt. Olympus, it probably would reform rather quickly.

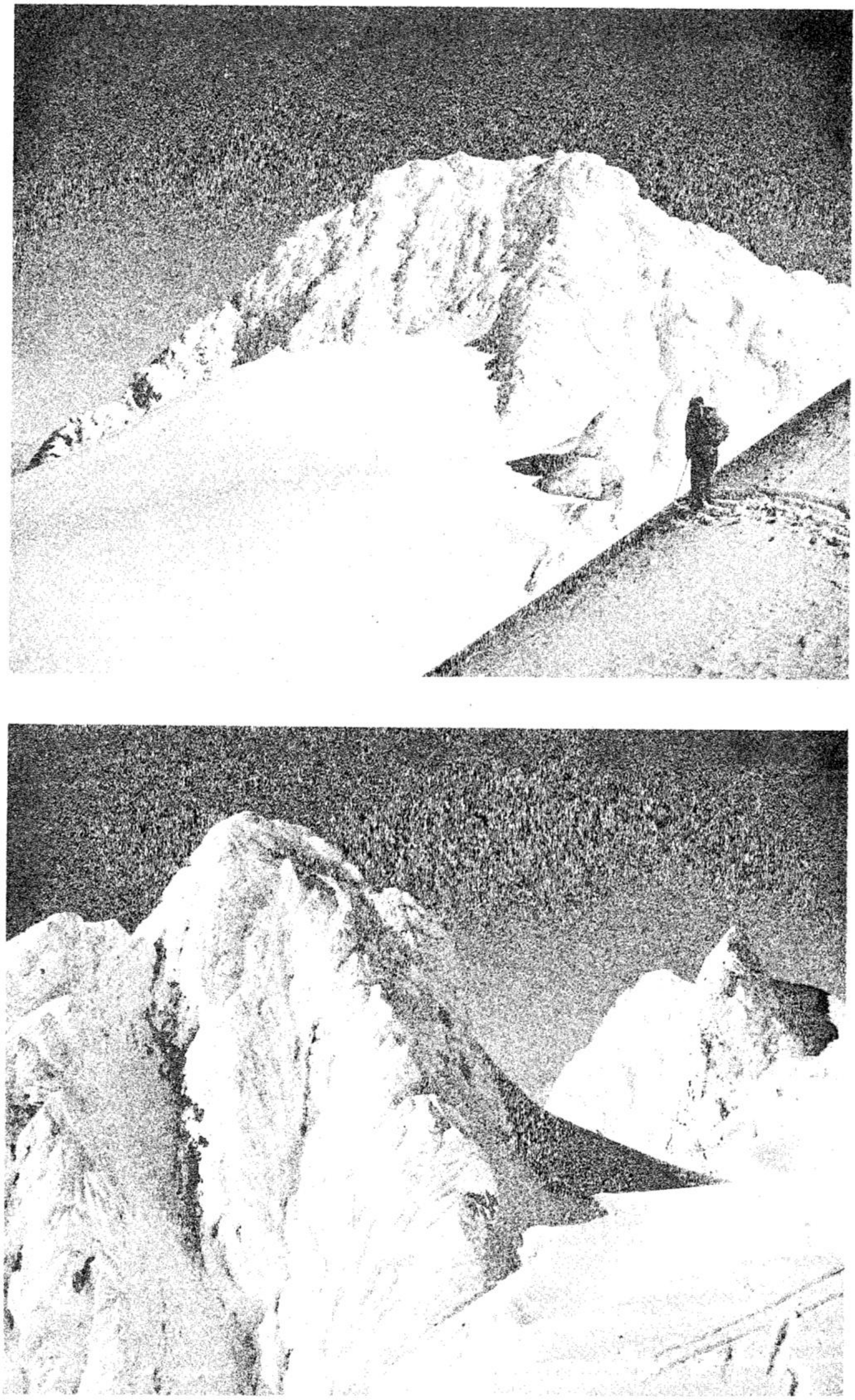

Figure 1- View of Blue Glacier

TABLE NO. 1

	August	September	October	November	December	January	February	Totals
Mean monthly temperature	41.6°F	49.0°	32.9°	29.1°	24.2°	25.4°	26.4°	
Precipitation	6.34"	6.43"	15.01"	11.15"	26.92"	30.74"	29.14"	125.82"
Snowfall		1.7"	21.6"	48.8"	117.5"	119.7"	108.0"	417.3"
Snow depth at end of month			6.0"	16.0"	109.0"	163.0"	207.0"	
Mean 24-hr. new snow density*			0.25 g/cc	0.17	0.25	0.24	0.23	

*Monthly sum of 24-hr. snowfalls divided into monthly total of water which fell in the form of snow.

TABLE NO. 2

Climatic Zone	Station	Total Precip. for 1 Aug 57 through 28 Feb 58	Aug-Feb normals (1931-1955)
West Olympic-Coastal	Blue Glacier	125.82 inches	
	Forks	80.80	85.86 inches
	Clearwater	74.81	
	Amanda Park	82.98	
	Aberdeen 20 NNE	92.45	93.62
	Spruce	93.08	93.27
	Cushman Dam	84.22	77.12
	Tatoosh Island	53.00	54.82
	Naselle	92.08	83.67
	Point Grenville	62.27	
Cascade Mountains-West	Cougar 1E	105.33	
	Wind River	81.66	74.95
	Cedar Lake	63.13	71.45
	Rainier Paradise	71.26	

THE ECONOMICS OF WATER SUPPLY FORECASTING

By

Carroll H. Dwyer[1]

When I agreed to prepare and present a paper on the "Economics of Water Supply Forecasting" I visualized a rather restrictive topic. However, when I began to study this subject I found that it had so many facets and ramifications that I have been hard-put to narrow the field to fit into the allotted time. Therefore, if I should not discuss or mention one of the facets you might be particularly interested in, it isn't oversight but simply that the subject is too large to cover in one paper. Should you wish to consider additional points, I'll be pleased to discuss them as time will allow in our discussion period.

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