

has most of the desirable features of electric heating and has a great advantage in energy costs. The greatest disadvantage at present is its first cost, and with a better understanding of its proper design and installation the first cost will probably be greatly reduced.

ACKNOWLEDGMENTS: The author wishes to acknowledge the assistance of two graduate students, Harvey Christensen and Arthur Presson, who made most of the calculations involved, and of the Bonneville Power Administration for the fellowships provided to carry out this study.

The original report, which includes several sets of curves and other data not presented in this paper, is available at the University of Washington as an Engineering Experiment Station Bulletin.



Meteorological Aspects of the Columbia River Basin Flood of 1948

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THE FLOOD OF THE COLUMBIA during May and June 1948 was the most disastrous in the history of this river. The toll: about 50 lives, nearly 50,000 people made homeless, about 10,000 homes destroyed or requiring much repair, close to 5000 acres of land lost from erosion, with an additional 19,000 acres badly damaged, and about 1000 miles of roads damaged. Property loss was conservatively estimated at \$100,000,000. No estimate has been made of the man-hours used to combat the flood during its rampage or of the man-hours lost because of the damage.

Flood waters at The Dalles reached the third greatest discharge rate since stream flow records began there in 1857; the floods of 1894 and probably of 1876 had somewhat higher water. Between 1894 and 1948 the maximum discharge of the Columbia did not exceed 800,000 second feet at The Dalles until 1948, when it reached 1,010,000 second feet on May 31. This was somewhat less than the 1894 flood, which had a peak discharge of 1,240,000 second feet. For more than 50 years there had been no floods of disastrous proportions; the general trend of peak discharge, again at The Dalles, was downward. What events led to the enormous discharge of 1948? How did they differ from other years? Will events of 1948 repeat themselves and bring other floods?

It is not necessary to point out that the area drained by the Columbia River receives more of its precipitation in the colder half year than in the warmer half. It is largely in the form of snow; the amount on the ground increases more rapidly than melting and evaporation can decrease it, until diminishing precipitation and temperature, mounting above freezing in spring, bring about the removal.

By April 1 usually there is a maximum amount of suspended water, as snow, at altitudes above about 3000 feet in the Cascades and at a somewhat higher altitude in the Bitterroots. Further, there is little snow left below 3000 feet and

the contribution of water to the river from the low snow has arrived at and gone down the numerous tributaries.

NORMAL SPRING WEATHER

OVER MOST OF THE BASIN, except in the high mountains, about the same precipitation, roughly 2 inches, falls over the area during April as rain. This amount, with stored soil moisture, is more than sufficient to keep the snow-free surface saturated; in fact, some run-off results. Temperatures average well above freezing below 4000 feet, but above that, freezing is dominant at night. Some snow will accumulate during April at the highest altitudes under normal conditions. However, during this month more snow melts than accumulates and the Columbia begins its seasonal rise from contributions of the higher tributaries.

May is different to some extent, especially with regard to temperature, for by the middle of the month snow is rapidly melting at all altitudes. The continued rise of the Columbia comes from this melt-water. The amount of precipitation is very nearly the same as April and comes as rain. Evapo-transpiration at low altitudes is sufficient to use all of the rain that normally falls during May. Hence, the mountain snow fields are responsible for the rapid increase of discharge of the Columbia and its tributaries.

Early June is an intensification of May conditions with a few scattered thunderstorms, most of them in the mountains. The peak discharge of the Columbia at The Dalles comes in June. The peak discharge is then largely a summation of snow-melt, and precipitation run-off in the mountains, with little, if any, run-off occurring below 2000 feet in June.

For the air during May and June, the normal sea-level pressure shows a fairly well developed thermal Low in the vicinity of Arizona with a shallow trough extending northward across the mountain states into Canada. The Pacific Northwest, hence the Columbia Basin, is dominated by a wedge of the Pacific subtropical High with its axis extending along a line joining Honolulu with Seattle.

Throughout the period, the Northwest is under the influence of anticyclonic flow. Aloft, the normal pattern consists of a strong westerly flow at both 10,000 and 20,000 feet over the Pacific and, though weakening somewhat over land, this westerly component is still maintained over the Columbia Basin.

WINTER AND SPRING WEATHER OF 1948

THE SPRING MONTHS of 1948 were far from normal. The snow had not built up at its normal rate during the early winter months and by the end of January

it began to look like only a "fair" water year ahead. At that time nearly all of Oregon had less than 80 per cent of average snow pack, but Washington had normal or slightly above normal snow depth-on-the-ground. During February more than normal amount fell over the Columbia Basin and a "good" water year was forecast as of April 1. Toward the end of March "high index" weather became predominant and storm after storm crossed the upper portion of the Basin. With the high wind speed from the west and with the temperatures below normal, the depth of the snow in the mountains increased rapidly. At the end of March, in Oregon, nearly three-fourths of all snow courses were above normal and about half of these had more snow than during the "good" water year of 1946. Washington reported snow on the ground "much above normal"; the same was true for western Montana and northern Idaho. Many Cascade Mountain stations had their maximum snow cover in March, some as late as the middle of April. As examples, Snoqualmie Pass, which on the last of March should have about 90 inches on the ground, reported 118 inches on April 11; Stampede Pass reported its maximum on the thirteenth. Instead of a decrease of suspended water, which should have begun at those altitudes by the first of April, snow, hence water, was accumulating. "Potential flood hazard" was forecast before the middle of April.

There was no warm weather during April in the Basin to start the snow melting. For the month, eastern Washington had a -4.2° departure; northern Idaho, a -3.0° departure; eastern Oregon, a -4.1° departure; western Montana, a -2.2° departure. Over the whole of the Basin the snow remained status quo. As late as the first of May, the snow depth at Snoqualmie Pass was 99 inches; at Stampede, 106 inches; and at Paradise Inn, 226 inches. (Because the Snake River, above the confluence with the Payette River, did not materially contribute to flooding the Columbia, we are disregarding conditions in southern Idaho.)

There was a well marked plus-departure of precipitation in April, which amounted to 1 to 2 inches in Washington, Oregon, and western Montana. Northern Idaho was literally soaked with an excess of from 2 to 4 inches. Because of this condition, the Weather Bureau pointed out in its Water Supply Forecast, issued as of May 1, 1948, that "flood hazards have increased on the Clark Fork-Pend Oreille, the Spokane and its tributaries, the Clearwater, the Kootenai, and the main stem of the Columbia River." In the Federal-State Cooperative Snow Surveys and Irrigation Water Forecast for Oregon, also issued on May 1, 1948, it was stated that "mountain snow cover was still ac-

cumulating, but the snow pack is ripe at the lower elevations and already releasing water . . . Statewide precipitation during April was 38% to 100% above normal . . ." Then followed a somewhat detailed revision of water forecasts, all of which were for *more water* than was forecast on April 1.

The characteristics of the departures from normal for April continued through the first half of May. Spokane did not report a maximum temperature above 70° F. until the sixteenth, but after the twenty-second most of eastern Washington and northern Idaho reported temperatures above 80° F. Although these high temperatures prevailed during the last decade of May, the first three weeks had been cold enough that minus-departures (from normal) were reported for eastern Washington, eastern Oregon, and northern Idaho. Western Montana was just above normal. Essentially, winter temperatures were predominant until the third week of May, when summer abruptly made its entrance.

All of April and the first half of May were cold, rainy, and snowy, but between the abrupt end of the winter precipitation pattern and the equally abrupt arrival of summer temperatures (at the beginning of the third week of May) the whole Columbia Basin was subjected to an enormously deep flow of warm, saturated air. This was repeated again in the last four days of May. The cold, wet, first half of May and the two wet periods at the end of the second and third decades of the month resulted in a very large plus-departure of precipitation for the month in the Columbia Basin between the International Boundary and the latitude of Boise. The main axis was the WNW. — ESE. line between Lake Chelan and Avery. The greatest departure reported, 7.67 inches, was at Davenport, Washington. The area where the departure was 5 inches or more covered several thousand square miles and extended into the headwaters of the North Fork of the Clearwater River of Idaho. The east slope of the Cascades had 2 to 5 inches more than normal; this also was largely true for both slopes of the Bitterroots. There was no departure in the Salmon Mountains.

Everywhere in the mountains the snow was "ripe"; it had been in this condition for a long time. It had long since passed the settled and loose-lying powdery stages. It was so well channeled that melt-water and rain could quickly penetrate the deep cover. The soil beneath was unfrozen and saturated and could not absorb any moisture being discharged by the snow. Snow and soil shed water like a soaked sponge.

CONDITIONS "ALOFT"

ON MAY 15, the pressure at 700 mb. (approximately 10,000 feet above sea level) was distorted from normal by the presence of a closed Low at 40° N.—142° W. Flow at the surface over the Northwest showed little departure in velocity or direction, but the flow off the Washington-Oregon coast was from the southwest rather than from the west. The Low "aloft" deepened rapidly and moved eastward until on May 18 it appeared as an intense trough over the Pacific Coastal states. With considerable variation in location and of intensity, this Low persisted in the Pacific Coastal area until June 15. Its movement was erratic, at times as far south as lower California and at others as far north as Canada. This Low brought a predominantly south flow on the east side and north flow on the west side to the Northwest as compared to the normal flow from the west quadrant. Whether this tropical air "aloft" came from the Pacific or Atlantic is not definitely known.

At 500 mb. (approximately 20,000 feet above sea level) the situation paralleled that at 700 mb. On May 15, the only evident departure from normal pressure distribution appeared as a trough roughly parallel to the 145th meridian. This trough deepened and moved onshore by May 18. A closed Low appeared over central California by 0400 o'clock on May 19 and continued to deepen for an additional 12 to 18 hours. Flooding rains resulted on its east side—the Columbia Basin. Following that, the Low filled partly, but persisted in the area until May 25, at which time another trough line appeared offshore with southerly winds reported by coastal stations. By the morning of May 26 the offshore trough had intensified, but remained offshore. Later that day a closed Low appeared off the Oregon coast which deepened somewhat and moved onshore. Little change of pressure occurred for 36 hours, but again flooding rains resulted. The trough did not completely disappear, but during the period of June 10 to 13, it again repeated the cycle of deepening and filling. For a third time flooding rains resulted.

Meanwhile, at the surface, a series of Low pressure centers appeared off the coast. Mean pressure maps for the period have not been drawn, but it is estimated that any constructed would show a departure from the long-time normal because of the number and persistence of Lows which invaded the region. No less than fourteen distinct fronts moved from the Pacific to the West Coast between May 1 and June 15. In every case the front had a north-south orientation which was parallel to the geostrophic winds at 700 and 500 mbs. Such a condition satisfies an observational rule of analysis that a cold front will have

associated with its widespread cloudiness and precipitation when it is parallel to the isobars at 10,000 feet. Cloudiness and precipitation will persist far behind the front because isobars "aloft" are parallel to the surface front; further, waves will form along such a cold front. (Cold occlusions behave in a similar manner.) Thus, cold or cold occluded fronts appearing on the West Coast during the period May 10 to June 15, entered a region in which they would be active; normally such fronts would be weakened as they entered the area.

In northern Idaho and western Montana there was another rainy period, in addition to the two mentioned before. The seventh and eighth of May produced the greatest amount of precipitation for a 24-hour period for many of the stations. The Kootenai River began a very rapid rise on the eighteenth of May at Leonia. The same is true of the Blackfoot River near Darby, Montana; the Middle Fork Flathead River at Essex; the Payette River, and the whole length of the Salmon River. The Clearwater River at Spalding similarly responded and also the Snake River at Clarkston, Washington.

Several of these streams reached their peak discharge before the end of May, especially the Kootenai, the Clark Fork, the Blackfoot, the Bitterroot, the Middle Fork Flathead River, the Clearwater, and the Snake. All of these streams are on the east side of the main stem of the Columbia. On the west side, the Wenatchee and the Yakima reached their peaks between May 29 (the Wenatchee at Peshastin) and May 31 (Yakima at Kiona). These and other tributaries brought the Columbia to the high crest at The Dalles and Portland on the thirty-first, a height which did not materially diminish for the next two weeks.

CONCLUSION

THE COMBINATION of events that produced the 1948 flood in summary is as follows: (1) There was more than normal snow by April 1, at which time the snow above 3000 feet should have begun to diminish; (2) April was cold and wet, with the accumulation of snow continuing; (3) The first half of May was cold and rainy, which prevented normal melting of snow and kept the soil saturated at altitudes where there was no snow; (4) Just after the middle of May a deep flow of warm, saturated air invaded the western states with convergence and lifting occurring to above 20,000 feet—excessive precipitation on ripe, well-channeled, and saturated snow resulted; (5) The same condition occurred again ten days later; (6) The first ten days of June were very warm; this produced enough melt-water to maintain an even, high discharge rate of the tributaries of the Columbia.

Will this combination of conditions repeat itself? Without hesitation, the answer is in the affirmative.



Contour Strip Cropping

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AFTER SIX YEARS of studying contour strip cropping in the Lewiston-Moscow area it is evident that this method saves soil, moisture, and fertility; it is the fastest, cheapest, and best way of farming; and, in short, it means more soil on the hills, and more money in the pocket of the farmer. There are several reasons for making such a statement. In the Genesee and Lewiston areas we have several good farmers who have been following fairly good conservation rotations and the use of crop residues for a number of years. On these farms we still find erosion. True, it is far less than their neighbors', but it is still excessive. The erosion is due to two chief reasons. One is the moist condition of the soil after sweet-clover fallow and the other is the excessively heavy storms on freshly prepared seedbeds, or excessive fall and winter moisture. These conditions do not occur every year; however, they do occur at frequent intervals and require further steps to reduce soil loss.

There are three ways of strengthening the erosion control program now employed on most farms: (1) Retire the land to a permanent cover of legumes and grasses. On steep land, retirement seems to be the only practical way. (2) Give more protection to the land by a system of field diversion. Diversions are expensive and hard to construct and maintain on the steep, rough topography of the Palouse country. (3) Apparently the most practical solution—contour cultivation and strip cropping. Under this method, the land is broken up into strips across the slope so that only a small portion of any hill is open to erosion at any one time.