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TORRENTIAL FLOODS
IN NORTHERN UTAH
1930

Report of Special Flood Commission
Appointed by Governor George H. Dern

Flood Damage by Parrish Creek at Centerville

Agricultural Experiment Station
Utah State Agricultural College
LOGAN, UTAH
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Janurary 15, 1931

Dr. E. G. Peterson, President,
Utah State Agricultural College,
Logan, Utah.

Dear Dr. Peterson:

On account of the recurring nature and the destructive character of the floods which have devastated property in Davis County and elsewhere in recent years, it appeared advisable to make a special study of the situation, I, therefore, in 1930, appointed a commission of citizens whom I deemed especially qualified, including practical engineers, geologists, foresters, and stockmen, asking them "to study the origin and cause of floods in Davis County and other parts of the state, and to ascertain whether any flood prevention measures are feasible".

The Commission has made a thorough, scientific, practical study and has submitted a report which I do not hesitate to praise for its thorough, unbiased informative and constructive character.

The Commission has no funds with which to publish this report, and I feel that in view of its public and scientific interest, and of the connection of the work of this Commission with the Forestry Department of the Agricultural College, that the publication of the report comes properly within the scope of the College. Therefore, I am writing to request that you have this report published as a bulletin of your institution.

Very truly yours,
GEORGE H. DERN.
Dear Mr.---------:
The recurring floods in Davis County and other parts of the State have done great property damage and have devastated and destroyed the homes and farms of many good citizens. Unless something can be done to prevent the recurrence of such floods they will be a continuing menace to the lives and property of people living in their path.

I believe it is important to have a thorough and dependable survey made by a group of competent experts and practical men to ascertain whether any flood prevention measures are feasible. Such a study must necessarily include the cause of the floods as well as the remedies. All phases of the problem should be subjected to the most careful scrutiny and scientific study. The existence of too many good citizens is involved to be anything but thorough in this research. I have therefore appointed the following commission to study the origin and cause of the floods, and to ascertain whether or not any flood prevention measures are feasible:

Sylvester Q. Cannon, Salt Lake Formerly City Engineer
K. C. Wright, - - Salt Lake Engineer, Chief of Construction, State Road Commission
Reed W. Bailey, - - Logan Assistant Professor of Geology, Utah State Agricultural College
R. J. Becraft, - - Logan Associate Professor of Range Management, Utah State Agricultural College
R. B. Ketchem, - - Salt Lake Dean of Engineering School, University of Utah
F. F. Hintze, - - Salt Lake Professor of Geology, University of Utah
C. T. Van Winkle, - - Salt Lake Consulting Engineer; Secretary, Utah Chapter, American Institute of Mining and Metallurgical Engineers
B. H. Prater, - - Salt Lake Chief Engineer, Oregon Short Line Railroad
L. D. Anderson, - - Salt Lake Chief Engineer, United States Mining and Smelting Co.

C. L. Forsling, - - Ogden Director, Intermountain Forest and Range Experiment Station, United States Forest Service
R. E. Allen, - - Provo Banker and Sheepman
Mark Anderson, - - Provo Business Man
Joel R. Parrish, - - Centerville Banker
David F. Smith, - - Centerville State Senator, Manager of Growers' Exchange
J. M. MacFarlane, - Salt Lake President, Utah Cattle and Horse Growers Association
George R. Hill, - - Salt Lake Agriculturist, American Smelting and Refining Company
L. M. Winsor, - - - Logan Irrigation Engineer, Division of Agricultural Engineering, United States Bureau of Public Roads
*H. C. Cosand, - - Salt Lake District Engineer, Denver and Rio Grande Western Railroad.

This work should be commenced immediately, and I am therefore calling the first meeting to be held in the Board Room at the State Capitol on Monday at 3:00 o'clock. I trust you will recognize the importance of this work, which possibly involves a permanent state conservation policy, and I hope you will be willing to give the state the benefit of your ability and time in ascertaining the facts so that the problem may be intelligently considered.

September 9, 1930.

Very sincerely yours,
GEORGE H. DERN.

*Mr. Cosand was unable to serve because of his absence from Salt Lake on official duties.
LETTER OF TRANSMITTAL

Honorable George H. Dern,
Governor State of Utah,
State Capitol Bldg.,
Salt Lake City, Utah

Dear Sir:

In accordance with the appointment by you of a Commission "to study the origin and cause of floods in Davis County and other parts of the State, and to ascertain whether any flood prevention measures are feasible", as per your letter of September 9th last, you are advised that the Commission has proceeded as follows:

The organization and procedure was unanimously agreed upon at a meeting held September 15th. A number of meetings have been held since that time. Two days were spent in the field by nearly the entire Commission: One in detailed examination of conditions on the watersheds of Davis County from which the heaviest floods came; the other in examining the flood control basins already built at the mouths of various canyons. In addition thereto various sub-committees and a number of individual members have spent much time and study of the various phases of the problem throughout the State.

In order to forestall the possibility of further damage in the Centerville area, we have already submitted to you, under date of September 30th last, a preliminary report with recommendations looking to the protection of that section.

We are now submitting the final reports of the various sub-committees with a summary of the findings, conclusions and recommendations by the Flood Commission.

Since my connection with the Commission has been largely that of a presiding officer, I feel free to congratulate you upon the wisdom displayed in the selection of the other members of this Commission. In my judgment they are unusually well qualified in their various fields and are modestly but efficiently doing a large part in the development of this State.

Respectfully submitted,
SYLVESTER Q. CANNON
Chairman, Flood Commission.

December 31, 1930.
TORRENTIAL FLOODS IN NORTHERN UTAH

Report of The Flood Commission

Attached herewith are the reports, as unanimously adopted by the Commission, on Ways and Means (Part I), Flood Control Works (Part II), and Causes and Prevention of Floods (Part III). Detailed study by the Commission has been confined to the Davis County section where the situation is now the most critical. Only general information was obtained on the floods in other parts of the State. In view of the importance attached to it, the Commission has dealt at some length in the second section of Part III with the occurrence and character of floods and the relation of plant cover and its depletion by overgrazing and fire to floods.

General Summary and Recommendations

The following summary gives in brief the findings and recommendations of the Commission. For fuller details refer to the cited pages of the several parts of the report.

1. The Commission concludes that the many floods in the State in 1930 were due to:

a. Uncommonly heavy rainfall which ordinarily occurs in a given locality only at intervals of several years to several decades. Rainfall much heavier than that of 1930 is probably extremely rare.

b. Topography and geological conditions favorable to sudden run-off and a large quantity of flood debris.

c. Scant vegetation on portions of the watersheds, due in some cases, as in Devil's Gate Canyon, to extensive rock outcrop; in other cases, as in the more arid parts of the State, to the natural sparseness of plant cover, often augmented by overgrazing and fire, and in many cases such as those in Davis County, to the depletion on critical parts of the watershed of the fairly heavy natural cover of vegetation by overgrazing, by fire, and to a small extent, by over-cutting of timber.

There is ample evidence on the watersheds of Davis County to show that had the plant cover been approximately equal to its original natural condition, the flooding in that section from the rains of 1930 would have been far less serious, if, not prevented. (Part III, pp. 16, 17).

This report received unanimous approval of the fourteen commission members present at the time of adoption. Shortly after transmitting it to Governor Dern, Chairman Cannon received from Mr. F. F. Hintze, also a member of this special commission, a letter in which he states: "I wish to indicate approval of the report, except as to parts of it which are not altogether clear to me and on which I may differ somewhat from other members of the committee."

Publication authorized by Director, January 16, 1931.
2. The Commission recommends the construction of barriers and settling basins at the mouths of the flooded canyons as the best means to control the high water and the debris it will otherwise deposit on valuable property during the spring run-off period and summer freshets and, insofar as possible, to control floods similar to those of 1930, pending the restoration of normal conditions on the watersheds. Each case will require individual study and expert direction for decision as to location, character, method of construction and expense justified. Barriers at the mouths of the canyons can not be expected wholly to control floods such as the more serious ones of 1930, but may be expected materially to aid in their control and are necessary to handle the high water, until flood prevention measures become effective. (See Parts I, II, and Part III, p. 18, paragraph "2")

The situation in Davis County calls for immediate action in order that land titles may be cleared up, the necessary funds raised and the work organized and gotten under way in time to have the works in place and ready for the spring run-off in May and June. This work is being tentatively organized under the leadership and direction of L. M. Winsor of the U. S. Bureau of Public Roads, but will require additional help from the State including legislative action, before it is placed on a permanent basis. There are other places in the State that need similar assistance.

3. Rehabilitation and maintenance of the plant cover on the depleted parts of watersheds is necessary for the abatement or prevention of floods. It is recommended (1) that grazing be eliminated for a period of years and otherwise to promote by seeding and planting, the restoration of the cover on approximately 5,000 acres of land at the headwaters of Parrish, Ford, Davis and Steed Canyons in Davis County, (2) that the cover be restored and maintained through more carefully managed grazing on an additional 10,000 acres and (3) that provision be made for fire prevention and suppression on the watersheds in Davis County.

Except for a relatively small acreage of federal, state or municipally owned area, the watershed land in Davis County is privately owned. Full assurance of regulated grazing and prevention of fire may be had only through public control of the watershed. It is recommended, therefore, that the local, state or federal government as soon as possible, acquire by purchase, exchange or, as a temporary expedient, the leasing of the 5,000 acres in worst condition and later extend the acquisition program to the entire west slope of the mountain in Davis County north of Centerville. (Part III, pp. 18-23).

4. The Commission further recommends the institution of a more definite flood control and watershed protection policy to give attention to the approximately 3,000,000 acres of important watershed land outside the present National Forests, and to definitely organize and carry out flood control work throughout the State. (Part III, pp. 23-25). Such a policy involves:

a. The appointment of a permanent Flood Commission to have powers as may be conferred, and also instructed to cooperate and
work with both state and national legislatures or officers, to secure laws, permits, grants, enactments or anything necessary to carrying out the plans essential in the prevention and control of floods in the State of Utah or connected with a permanent conservation policy (Part III, par. 1).

b. The appointment of a Conservation Survey of competent experts, as a part of or to work with the permanent Flood Commission, whose duty it will be to study flood control and prevention problems and make recommendations as to their solution. (Part III, p. 25, par. 4).

c. The extension of public ownership to the little protected parts of the 3,000,000 acres of important watershed land outside the National Forests and organization for the management of State owned watershed lands. This may require legislation to authorize the State to acquire, exchange for and regulate the use of watershed lands and will require the appropriation of funds for purchase of lands. The National Forest Reservation Commission might also be authorized through Federal legislation to acquire and administer additional watershed lands in the State. (Part III, p. 25, par. 1).

d. Strengthen the present state fire law approved March 14, 1927. (Part III, p. 25, par. 2).

e. Legislation creating flood districts and other means for the satisfactory carrying out of flood control plans. (Part 1, par. 8, and Part III, p. 25, par. “3”).
f. The stimulation of better management of privately owned lands and of research in flood and watershed protection problems. (Part III, p. 26, par. "5" and "6").

g. Amendment of public nuisance laws to apply to flood problems. (Part III, p. 26, par. "7").

5. The Commission has not attempted to arrive at the probable cost of flood control works, value of the land that should be acquired or details as to the cost of the damage done by floods. The cost of prevention and control that is justified will have to be determined in each individual case. However, it seems obvious that the cost of both control works, and acquisition of land recommended for Davis County will not approach the damage done to property alone in that locality in 1930, to say nothing of the loss in business and commerce, general decline in property values and the adverse advertising the State received, which are difficult to evaluate, and the mental anguish of the people who reside near the mouths of the canyons, something not measurable in dollars and cents.

SYLVESTER Q. CANNON,
Chairman, Flood Commission.

December 29, 1930.
Report of Committee on Ways and Means

We, your committee, hereby report our findings as follows:

Recommendations

1. That the Governor appoint a Flood Control and Prevention Commission as a part of a permanent state conservation policy; commission to have immediate powers as may be conferred, and also instructed to cooperate and work with both State and National legislation, or officers, to secure laws, permits, grants, enactments or anything necessary to carrying out the plans essential in the prevention and control of floods in the State of Utah or connected with a permanent state conservation policy.

2. That immediate relief be given the flood districts by taking care of the debris at the mouths of the canyons where such floods have, and are still occurring; manner of such relief to be outlined by your special Committee under L. M. Winsor.

3. That this, or the permanent Commission visit the Southern Utah flood districts and study their conditions carefully.

4. That each County and Community have a definite Fire Control policy of a permanent nature an organization that may be called into action whenever any condition may warrant.

Water Sheds

5. Return to Government, State, City, or County control, as your special Committee recommends.

Finance for Control at the Mouths of Canyons

6. Cooperation of all property owners in flood district, both financially and in securing title to lands necessary to be used in control of flood waters.

7. Expense to be divided among the property owners of the district, State, Government and State Road Commission, County School Districts, railroads, or any other parties interested; such proportions to be determined by parties concerned, if possible.

8. Legislation creating flood districts making it possible to tax property to help create and maintain flood control for the good of all; such protection not to be hindered by a few.

Your Committee has not gone into further detail because of the fact that your other special committees will have their own recommendations.

Respectfully submitted,

COMMITTEE ON WAYS AND MEANS

JOEL R. PARRISH. Chairman
DR. GEORGE R. HILL
DAVID F. SMITH
MARK ANDERSON

Woods Cross, Utah
Sept. 29, 1930.
PART II

Preliminary Report of Committee on Flood Control Works

In connection with the recurrent and persistent floods in Utah during July, August and September, 1930, a condition has developed which requires immediate action if further damage is to be prevented. The heavy floods have opened up definite and open channels leading all the way to the crest of the mountains, which provide a ready passageway for run-off during periods of storm.

Deep gorges have been cut through beds of sand and gravel under the various levels of Lake Bonneville, leaving vertical banks forty, fifty and over one hundred feet high. These are caving badly already, bringing down vast volumes of debris to be moved into the valley below by the next flood or during the period of high water which will come with the melting snows next March and April.

In the present condition each storm brings a spurt of high water which carries mud, sand and gravel around homes and over lands adjacent to the flood swept districts. This is particularly true in two or more sections in Davis County where heaviest loss was sustained during the July and August floods.

In order to provide a means of protection against the inevitable additional damage which must follow if nothing is done it is recommended that a system of barriers and controls be constructed which will hold each flood stream within certain prescribed limits, causing the burden of debris carried out of the canyons to be deposited over an area of land set aside for that purpose. Each flood has left a huge scar thru the otherwise unbroken strip of fertile orchard and truck garden lands extending from Bountiful to the north, even as far as Perry, near Brigham City. These blots on the landscape are strewn with boulders and flood debris to such an extent as to make reclamation of the areas thus laid waste unprofitable, if not impossible. In most cases the devastated areas offer the best solution to the problem of choosing a site which may be devoted exclusively to unloading future floods or high water streams.

If the burden of debris can be separated from a flood stream it is not difficult to make the water stay within the limits of a channel; but when the stream is laden to capacity with boulders, sand, gravel, logs and brush the ordinary channel is rapidly filled and obliterated and the stream spreads at random over on either or both sides. As the stream spreads after being liberated from the confining channel within the canyon walls, its velocity is checked and it begins to unload. The larger, heavier boulders drop out first as the current is checked. The unloading process is made complete only when the flood stream passes into a pond or lake of comparatively still water. (See Fig. 2).

This principle or law in nature is utilized in the system of flood control herewith prescribed as the solution of the problem now confronting the people in the flood swept regions of Utah. In making
Fig. 2.—Typical flood barrier and spillway, showing pond in which gravel and debris are deposited. Farmington Creek, 1927.

this recommendation it is recognized that the system of flood prevention, as prescribed for the water sheds, will be slow in becoming effective and that in the meantime further damage of very great magnitude can be prevented only by providing such a system of control as the one outlined.

Each flood stream and each flooded area must be studied separately and details must be worked out in harmony with existing conditions.

Roads, improved property adjacent to the stream course, and topography are some of the principal factors which limit the design. In the main, however, the same system may be followed.

It is recommended that a marginal dike be erected on either side of the area which is set aside as a flood way, and that the stream be liberated at the mouth of the canyon to spread at will between these borders. At the lower end of the area a barrier must be placed which is high enough to provide a shallow pond or pool of quiet water thru which the stream must pass in order to complete the process of unloading fine sand and silt. (See Fig. 2). A spillway will return the stream to the channel where it passes on under highways or railroads, or where it may empty into irrigation canals as the case may be.

In such a system of control it is evident that the marginal dikes must be maintained well above the level of the cone or fan which will rapidly form below the mouth of each canyon where the stream spreads and unloads. This is essential (1) to prevent the stream at high water stage from spreading beyond prescribed limits, and (2) to make adjacent property secure against the hazard of recurrent torrential floods which may follow as long as conditions over
the watershed are such as to make such floods probable. Likewise, the barrier at the lower end of the depository must be raised from time to time so as to provide the basin of quiet water so essential to a complete unloading of the flood stream. There are various ways by which these embankments may be raised. The system which has proved to be most economical is to make the flood stream build in part or in the main, its own embankment. This is done by building a double embankment on either side of the depository. The stream at high water stage is then made to flow around the outer edges of the depository until the space between the double dikes has been filled. The material thus deposited is then moved to either side and the process is repeated. The limit of height to such an operation is governed only by the amount of heavy debris which the stream carries.

This system of building embankment has been used with signal success at Willard following the flood of August 13, 1923.

Definite recommendations are made at this time covering two of the most urgent cases in Davis County.

Parrish Creek Area

At Parrish Creek conditions are rather flexible. In other words the proper location of border dikes and barrier is not limited to an exact locality. Details as regards land ownership within the area to be devoted exclusively as a floodway, may and should be considered in determining the course or location of each dike. The barrier embankment and the spillway may be located at any point between the state highway and the locality immediately east of the district school building. In general the border dikes should extend from the mouth of Parrish Canyon on either side of the flood swept area to a point near or below the district school—the farther west the better. The border dike on the north may readily be made to swing to the south as to leave the school building well to the north of the depository, in which case the barrier and spillway may be located even as far west as the east boundary of the highway. The east end of the north dike must be carried well up to the high ground at the mouth of the canyon in order to save the homes and orchards in that locality from destruction by further floods.

In addition to the barrier a channel must be cut to lead the stream when unloaded under the highway and beyond the three railroads.

Ford Creek Problem

At Ford Creek the state highway is too close to the mouth of the canyon to permit of providing a system of complete economic control confined entirely to the limited area above the road. In this case it seems desirable that the main depository be located below the highway and above the interurban railway. It is necessary, however, that the regulation border dikes extend from the mouth of the canyon to the highway as well as from the highway on down to the
interurban tracks. It will be desirable to build a barrier above the highway, however, in order that the stream may be collected and passed over a spillway and thru a bridge or culvert beneath the road, where it may again be allowed to spread and thus complete the process of unloading before it reaches a second barrier and spillway which should be located immediately above the interurban tracks.

In reconstructing the highway over Ford Creek, which undertaking is already under way, there should be provided a dip or submerged crossing in the grade now being constructed. This dip should be four or five hundred feet long and about three feet deep, in order to make sure that a recurrent flood, which may be too big in volume to be passed over the spillway and thru the culvert,—may be kept from spreading beyond prescribed limits as it passes over the highway into the depository below.

With this type of control above the road there is no apparent difficulty in the way of providing for complete control in the area below.

Other Streams in Davis County

A similar condition to that at Ford Creek exists at Davis and at Steed Creeks and the problem may be worked out in the same general way. Details, however, must be worked out on the ground.

Streams in Other Districts in Utah

Devastating floods have laid waste many sections of Utah during the past ten years or more. Certain of these areas have already been placed under partial or comparatively complete control. Additional work should be done on most of the structures already in operation, and a crying need exists for help in solving other recent problems, such as that at Salina, and at numerous other points farther down the state.

L. M. Winsor
B. H. Prater
R. B. Ketchum
Committee
PART III

Report of Committee on Causes and Prevention Measures

The committee assigned the task of preparing the report upon the causes of, and upon the prevention measures for, the recurring floods in Davis County and other parts of the State report as follows:

SUMMARY

Causes of Floods

The committee concludes that the causes of the many floods throughout the State in 1930 were:

1. Uncommonly heavy rainfall.
2. Steep topography and geological conditions conducive to sudden run-off and to a large quantity of flood debris.
3. Scant vegetation on portions of the watersheds of the canyons which flooded, due in some cases to the natural barrenness or semi-barrenness of the land, but in many cases such as those in Davis County, to the depletion of the natural plant growth, by overgrazing, by fire and to a small extent by over-cutting of timber.

The rainfall was uncommon in that such heavy and rapid precipitation on the average probably does not occur in a given locality more often than once in several years to several decades. It is reasonable to believe that approximately equally heavy rains have occurred many times on the Davis County watersheds and in many other localities in the State during the past several centuries and several times since the State was first settled. Such rains occurred in Davis County in 1923. But probably not for several decades prior thereto.

In general, other things being equal, the degree of surface run-off from heavy rainfall varied roughly with the sparsity of the plant cover on the slopes of the watersheds. In some cases such as Devil's Gate Canyon on Weber River, the floods originated on the extensive barren rock outcrops on the drainage, and depletion of the cover was not a factor. Some of the other floods, such as the ones in the north edge of Salt Lake City, originated on the foothills on a combination of bare rock outcrop and soil surface that had been heavily depleted of vegetation by overgrazing and fire.

Extensive areas of low mountain and foothill lands more especially in the southern part of the State, naturally have a relatively sparse cover of vegetation chiefly because of a low average annual precipitation. These semi-arid regions are sometimes visited by summer rains sufficiently torrential to cause surface run-off of flood proportions from the naturally sparsely vegetated slopes. The cover on much of the area has been further thinned by overgrazing and fire thus accentuating the conditions favorable to abrupt run-off from
torrential rains. Heavy floods are naturally of rather frequent occurrence in these semi-desert regions, although they have been intensified in degree by the depletion of cover. These floods have received but minor publicity in the past because they are the usual rather than the unusual and their paths are avoided as much as possible. Some of the floods of 1930 in the State came from semi-desert areas naturally having sparse plant cover.

Many of the more disastrous floods, and especially those in Davis County from Bountiful to the mouth of the Weber River, originated on the high part of the mountain watersheds where rock outcrop is a negligible factor and where natural conditions are favorable for a fairly heavy stand of plant growth, but which had been heavily depleted or denuded of vegetation on critical areas. The maximum plant cover that can be grown upon watersheds capable of sustaining a uniformly fairly heavy stand of forest, shrub and herbaceous plant growth, may not have the capacity to prevent serious floods from the most extreme rainfalls. There is, however, ample evidence on the watersheds of Davis County to show that had there been a mantle of vegetation practically equal to the original natural cover, the serious flooding in that section from the rains of 1930 would have been greatly diminished, if not prevented. Geologic features emphasize the extreme rarity if not the lack of precedence in recent geologic times of floods like those of 1923 and 1930.

In the deposits at the mouths of canyons is written the record of the rate and amount of erosion and deposition from floods that have gone on during the past ages. The texture, structure and form of these deposits show that the floods of 1923 and 1930 in Davis County mark a distinct increase from the normal rate of erosion and deposition of the thousands of years since Lake Bonneville receded to the present level of Great Salt Lake. In depth of cutting, in quantity of material and size of the boulders carried, these floods far exceed the normal occurrence since the recession of Lake Bonneville. The post-Bonneville alluvial deposits are small, and the quantity of material brought down and added to them by the 1923 and 1930 floods is all out of proportion to the amount brought down through the thousands of years of post-Bonneville history. The conspicuous displays of boulders and the prominent humps such as some which are traversed by the State highway are commonly referred to as evidence of pre-historic floods of the post-Bonneville epoch, but upon examination are found in most cases to belong either to the pre-Bonneville or the Bonneville stage of erosion and deposition. If floods had occurred at intervals of one-half century for the 30,000 or more years since the recession of Lake Bonneville, the alluvial structures would be found extending far out into the lake. In other words, floods like those of 1923 and of 1930 have not been normal occurrences of each century in the past and the cause of their occurrence in recent years is to be looked for in changes from some previous condition. These changes are found in the plant cover of the watersheds.
Plant cover conditions are such in numerous places throughout the State that floods will almost inevitably follow a rainfall equal to the flood storms of 1930. Many places were not flooded in 1930 due only to the lack of the necessary heavy rainfall. Rain storms yielding a quantity and rate of precipitation sufficient to cause floods even where the surface of the ground is practically bare, are characteristically local in nature and usually occur only at intervals of a few to many years. However, such storms may be expected to occur again in the places where they occurred in 1930, and in other places in the State. In fact, the recent floods have left the watersheds in Davis County in such a condition that materially lighter rains than those of 1930, should they occur in the next few years, will result in severe floods.

Plant cover is the only one of the three major factors in relation to floods that is subject to human influence, except as dams and basins can be used to control run-off.

Prevention and Control Works

The present situation in Davis County is such as to call for steps to:

1. Eliminate grading at least for a period of years, protect against fire, and otherwise promote revegetation of the critical areas of the watersheds from which came the bad floods of 1930. Except in extreme cases of denudation or of other special circumstances, revegetation of depleted areas ordinarily can be accomplished by the exercise of careful range management and control of fire, but conditions are so bad on approximately 5,000 acres of the watershed and such high values are involved on the endangered areas below, that exclusion of grazing is needed for a period of years.

2. Erect control works at the mouths of the canyons that have flooded, commensurate with the property values involved, to control the debris that will be washed onto the farm lands and other property at the mouths of the canyons by high water in the spring, and by summer freshets and insofar as possible, to control summer floods that may occur until such time as adequate vegetative conditions have been restored on the watersheds.

The situation throughout the State is such as to require the development of a watershed protection and flood control policy which will ascertain the needs and which will develop and carry out State-wide plans to develop security from flood losses and from damage to the water supply.

The fact that the removal of the cover by overgrazing is responsible in so great a measure for the present denudation of watersheds and consequent floods in Davis County, and that exclusion of livestock from these watersheds for a period of years is needed, should not be construed as implying that well managed grazing is injurious to watersheds. There are ample demonstrations throughout the State that, except where there are special conditions, carefully managed grazing may be practiced without injury to the watersheds. In fact,
careful grazing and thoughtful herdsmen are an added protection against damage by fire. The floods in Davis County, however, are a severe indictment of abuse of range lands that leads not only to floods, but to the depletion of the forage supply as well. Such depletion is uneconomical to the livestock producer. The livestock industry itself should cooperate in the correction of bad situations wherever they occur.

Recommendations for Davis County Watersheds

The committee recommends and urges, as means and methods for abatement and prevention of floods in Davis County, the following:

1. The acquisition by the State or Federal government of the critical watershed lands for the protection of both private and public interests. Except for a small acreage of remaining open public land and State and municipally owned lands, the area is in private ownership. Public control of all the land is necessary for the restoration and maintenance of an adequate plant cover and other flood prevention measures. The interests at stake are more than local in character since recurrent floods will destroy public as well as private property, endanger the lives of the citizens and seriously interrupt transportation and business. Protection of property, life and commerce, and the acquisition of land to that end are a public responsibility.

The public acquisition program should begin with immediate acquisition by purchase, by exchange or, as a temporary expedient, by lease, of approximately 5,000 acres of land at the heads of Parrish, Ford, Davis and Steed Canyons. (Fig. 3 "A"). These lands would embrace the denuded and semi-denuded lands from which the worst floods came. Subsequently, as soon as orderly financing will permit, a second area comprising approximately 5,000 acres in the head of Farmington Canyon should be obtained to protect the headwaters of this stream. (Fig. 3 "B"). A third area next in order of importance in an acquisition program comprises approximately 5,000 acres adjoining the summit on the west slope of the mountain between Farmington Canyon and Weber Canyon from which many floods came in 1923 and 1930. (Fig. 3 "C"). The remaining entire west slope of the mountain from the summit down approximately to the upper limits of ancient Lake Bonneville, from Weber Canyon to the south limit of Centerville Canyon, an additional 17,000 acres should eventually be acquired. These lower slopes which have a fairly dense stand of brush, are primarily valuable for watershed protection, have only minor value for grazing, and although not in bad condition at the present time, should be acquired to insure permanent protection. Moreover, acquisition of the entire slope would simplify public administration. This is a total of approximately 32,000 acres of land to be acquired eventually, of which approximately 4,500 acres are now either open public domain or are State or municipally owned.

The State, with the aid of the counties involved, may be the
Fig. 3.—General map of area studied. The critical watershed areas of Davis County lie to the right and above the eastern projection of Great Salt Lake.
proper agency to carry out the acquisition program, in which event funds for purchase of the most critical area should be made available at an early date. There is merit also in the acquisition of the lands by the Federal government. The lands involved are of a character that should not have been passed from public to private ownership by the Federal government as was done with considerably more than half the area; the lands are chiefly valuable for water-
shed protection and as potential forest lands; and the Federal government, which is already managing like lands in the State, will be able most economically to administer them.

The land to be acquired should be appraised by a public agency and if necessary condemnation proceedings be brought to prevent delay.

2. Exclude grazing for an indefinite number of years on the 5,000 acres at the head of Parrish, Ford, Davis and Steed Canyons, until satisfactory watershed conditions have been restored. It is probable that a cover can be restored within a reasonable time on the remainder of the Davis County watershed by carefully regulated grazing and by fire protection, without the exclusion of livestock.

3. Aid in the restoration of a cover by the seeding and planting of suitable grasses, weeds, shrubs, and trees and further check sudden run-off and erosion by the construction of brush dams and other minor works on the more denuded parts of the watersheds. Certain plants such as brome grass, Kentucky bluegrass, mountain brome grass, dandelion and other plants, including shrubs, should take root and grow on the denuded places where natural revegetation would be a slow process. Some research might be necessary to find the species best adapted but this could be accomplished without difficulty. Brush dams, small terraces, and other minor control works could be installed in strategic places at small expense to hasten the process of restoration to normal conditions. Eventually forest planting could be undertaken to advantage and with profit to the community. A forest cover will offer the greatest security but it will require several decades before newly planted trees would become effective. The other vegetation and minor control works will afford much earlier relief. Approximately $5000 a year for from five to ten years could be expended with profit in seeding, planting and control works. This locality offers one of the greatest opportunities available for demonstration and research on grazing, and erosion and flood control by State and Federal agencies engaged in such work.

4. Establish effective fire prevention and suppression measures. Present conditions with respect to fire could be materially improved on the entire Davis County watershed in any event, by a conscientious application and enforcement of the State fire control law approved March 14, 1927. However, the inactivity in applying the provisions of this statute throughout the state plainly shows the need for strengthening the administration of this law. Placing the area under Federal jurisdiction similar to that on the National Forests would automatically result in the application of fire control measures.

The foregoing measures will not afford immediate results in flood prevention. The restoration process will require a number of years. In the meantime floods may be expected should heavy rains occur, the seriousness of which will depend in considerable measure upon the revegetation that has taken place. Catchment dams and basins offer the greatest security against such emergencies. It is expected that eventually the cover will be restored and the danger of serious floods from rains like those of 1930 should be eliminated.
Fig. 6.—Head of flood deposit at Ford Creek, showing mud flow and character of materials.

The establishment of a cover is impossible and does not offer a solution for floods in Devil's Gate and similar canyons. The bare rock exposure in this canyon offers no opportunity for plant growth and floods may be expected whenever excessive rainfall occurs. The only aid which can be rendered in such examples is the construction of works to divert and control the floods and to avoid occupation, insofar as possible, of the area in the path of the floods.

A State Policy for Watershed Protection and Flood Control

The increasing menace to life, property and commerce, and the damage being done to the water supply, as exemplified by the floods of 1930 in Utah, calls for the institution of a State-wide watershed protection and flood control policy to correct the present unsatisfactory condition and to avoid if possible a more perilous situation in the future. Many areas which were flooded in 1930 have not received the attention needed and should receive first consideration in a State-wide plan.

The Public Interest

The majority of the citizens of the State are interested in the greatest security that can be afforded against floods and in the perpetuation of a usable water supply. Denudation of watersheds contributes both to the occurrence of floods and undesirable conditions of run-off for irrigation, domestic use and hydroelectric power development. A great many of the homes, farms and towns, and a large proportion of other property in both private and public ownership are so situated with respect to the mountain streams as to be
FIG. 7.—Looking downstream in one of the canyons in Davis County from a point approximately three quarters mile below the head of the canyon. These slopes are well-covered with shrubby aspen, patches of conifer timber, "chaparral", oak, and undergrowth. These slopes contributed practically nothing to the floods which swept this canyon. The floods came from the head of the canyon above point at which photograph was taken.

menaced in a greater or less degree by flood run-off should it occur. The dependence upon a maximum usable streamflow for various purposes is self-evident.

Watershed protection is intimately associated with grazing, the basis of one of the leading productive industries of the State. Consequently protection should not and need not be carried to the unnecessary extreme of excluding all grazing from watersheds. The situation is such at the present time, however, due to many complicated features under which some of the lands are utilized, that the public interest is not being safeguarded. Moreover, there is not being applied, on a considerable area of watershed land within the State, the fire prevention and control measures that the public interest requires.

The total land area of the State is 52,598,000 acres. Approximately 16,000,000 acres, exclusive of the lower lands in the Colorado River drainage, or about one-third of the total area of the state is land requiring consideration for protection of watersheds. Of this third, about 11,000,000 acres are of primary importance as watershed; of
this approximately 8,000,000 acres are in National Forests, Indian Reservations or National Parks, leaving about 3,000,000 acres of highly important watershed land in private, state or public ownership upon which no watershed protection measures may be applied at the present time. Although all of the National Forest land may not be in as good condition as it should be for watershed protection, it is susceptible to the application of the necessary measures. It is the remaining 3,000,000 acres of highly important watershed land and the 5,000,000 acres of secondary importance that requires the greatest attention.

The essentials of a policy for this land are as follows:

1. The extension of public ownership and control to the little protected part of the 3,000,000 acres of important watershed lands outside the present National Forests. This involves (a) placing all important watershed lands in the State that are still in the open public domain under some adequate system of public control. (b) Acquisition by the State or Federal government of important watershed lands now in private ownership. This may be accomplished by purchase or the exchange of present State or Federal lands of minor watershed value for lands of high watershed value. If acquired by the Federal government the lands should be added to existing National Forests. The present laws pertaining to State lands, if necessary, should be modified to permit purchase and exchange and the administration and protection of State lands for watershed protection purposes. The State should set an example of watershed protection on its lands.

2. The strengthening of the State fire law, to insure adequate fire prevention and control on private and State owned watershed lands. The present fire law is ineffective in most counties of the State due to lack of initiative on the part of the citizens and officials of the counties. This should be remedied.

3. An organized plan for the construction of flood control works wherever needed, including means for financing and for revising State laws to meet the complications involved in property rights, etc. There are many places in the State where flood control works need to be constructed and maintained. Any effort is now complicated by property rights. No means of orderly financing has been developed. The responsibility for actual construction of control works should be definitely fixed.

4. The establishment of a Conservation Survey, the duties of which will be (1) to study all places in the state where floods have occurred, (2) to make recommendations as to need, (3) to study and to classify watershed lands and to declare as to the likelihood of floods from them and as to their need for protection, (4) to make recommendations to the State Land Board as to areas for acquisition, and (5) to make further recommendations as to the need for the construction of flood control works. There should be some responsible agency composed of competently trained experts, subject to call when needed to make examinations and to report upon the need in various flood
problems. Such an agency could well be made up largely of men already in State employ, requiring funds only for traveling expenses and for other special purposes in connection with flood problems.

5. The stimulation of better management of privately owned lands through the Utah State Agricultural Extension Service. The Extension Service of the Utah State Agricultural College is now rendering some assistance through its county agricultural agents in encouraging the adoption of improved methods of range management. Much more can be accomplished through this sort of cooperation between the State and the private land owner toward obtaining a more widespread application of range management that will afford watershed protection.

6. The enlargement of research work, both Federal and State, in the study of the watershed protection problem. A small amount of work is now being done by the Research Branch of the Forest Service and by the State Agricultural Experiment Station. Far more research is needed to find out such things as the full limits of the influence of plant cover on floods, streamflow and erosion, methods of restoring vegetation on denuded watersheds or increasing the vegetation where it is naturally sparse, the methods under which the forage and forest cover may be used without injury to the watershed or the water supply, the best methods to use in the control of floods and erosion where it is now occurring to the extent that surface runoff is being hastened, and many other phases of this vital problem.

7. It has been suggested that the public nuisance laws of the State be amended to make possible public intervention where privately owned land is being abused to an extent that a public menace is being created. It appears that there should be some means of legal recourse to protect the public interest.

FLOODS IN UTAH

In view of the magnitude and importance of the problem and for the sake of a clear understanding of the grounds upon which the committee has drawn its conclusions, the findings are presented in some detail in the following pages of the report:

The Occurrence of Floods in Utah

Floods occurred during the summer of 1930 in various localities throughout almost the entire state. The first floods of the year were on July 10 in the Davis County section between Centerville and Devil's Gate Canyon, a tributary of Weber Canyon. All of the canyons that head near the summit on the west front of the Wasatch Range between these two points, flooded heavily. The worst damage occurred at the mouths of Parrish, Ford (or Ricks), Davis, Steed and Devil's Gate Canyons. There was also some heavy run-off on July 10, from the foothills between Parley's and Emigration Canyons east of Salt Lake City, causing slight damage to the highway and in the city. Severe floods occurred again from Parrish, Ford, Davis and Steed Canyons on August 11 and 13 and on September 4
Other localities visited by floods during the July 10 to September 4 period, include quite serious floods along both the east and west parts of the Oquirrh range, more especially at Bingham Canyon, Magna, Garfield and in Ophir and Mercur Canyons. Still other places rather seriously flooded include the north edge of Salt Lake City, Big Government Canyon near Goshen, Snow Slide Gulch in Provo Canyon, Rock and Slate Canyons between Provo and Springville and at Hurricane. Less severe floods occurred during the period at Provo, between Ogden and Willard, in several tributaries of East Canyon west of Morgan; near Alpine; at Grantsville and Tooele; near Moroni and Silver City in Salina Creek, and in Chalk Creek near Fillmore; over the Fish Lake highway and in Castro Canyon just south of Panguitch. On the Green River drainage there were floods in Price River, in Cottonwood Creek near Orangeville, near Mt. Emmons in the Uinta Basin, and in Mill Creek, Pack Creek, Indian Creek and Cottonwood Creek in the Grand-San Juan section.

Floods almost as serious as the one of July 10, 1930, occurred on August 14, 1923, in Farmington, Steed, Davis and Ford Canyons and on the same date in Willard and Perry Canyons. Overgrazing and fire are reported by Paul and Baker as having been important causal factors in the floods of 1923.

It is reported that a flood of some consequence occurred in the Davis County section in July, 1877, and another one as far back as the early sixties. Local residents who saw the floods of 1877, 1923 and 1930 report the flood of 1877 as being much the smallest. The geologic evidence does not indicate that the earlier floods were anywhere near as large as those of 1923 and 1930. Neither is there any evidence to show what the conditions of plant cover on the mountain slopes were from 1860 to 1877. In this connection it is interesting to note that history of Davis County is replete with records of the large number of livestock being grazed after the first settlement in 1847 as well as of the ravages of grasshoppers or crickets. Fire also may have been a factor during the early days of settlement.

The more detailed study has been confined to the floods which occurred along the Wasatch front from Parley's Canyon to Devil's Gate in Weber Canyon. Less detailed reports have been obtained on many of the other floods which occurred in the State during the season of 1930.

Character of the Davis County Floods

The more destructive floods which reached the valleys in Davis County were characterized by mud flows or water containing enormous loads of boulders, stones, gravel, sand and finer material. The damage to property was done largely by this material rather than by excessive high water. The great bulk of the flood water accumulated on the headwaters of the tributaries of each of the comparatively small canyons, mostly within three-fourths of a mile of the moun-

Fig. 8.—View of one of the steeper slopes at the head of Ford Canyon, showing evidence of heavy runoff from the denuded areas, of less heavy runoff from the partially denuded areas (center), and of light runoff from the areas fairly well covered with brush.

tain summit. The water as it poured down the ravines picked up a large quantity of earth, stones, and up-rooted vegetation. The water and solid materials swept down the tributaries and from their confluence down the main canyon, excavating much of the old filled-in material upon which the former streams had been for centuries established. The recent gullies in the canyon bottoms now extend to bedrock for long continuous stretches, in some places reaching a depth of over 75 feet. This erosion of the mountain slopes and the canyon bottoms, together with heavy cutting of the deposits at the mouths of the canyons, contributed the material for the mud flows which emerged onto the land at the mouths of the canyons. The advance portion of at least the first mud flow in each canyon was a thick mixture barely fluid enough to flow, no free water going before it. The front, as well as the sides of the moving mass, was
several feet high and had rather abrupt front and side walls. When this flow reached the gentler slopes in front of the canyons its velocity was decreased and material began to be deposited. The less thick mud and water which followed swept over the initial deposit, eroding a channel through it and later spreading out in fan-shape on the still gentler slopes farther away from the canyon mouths. The water, without the solid material and with a somewhat longer period of run-off, probably would have been contained in the natural channel of the stream and little or no damage would have been done.

It appears advisable also to point out that there were no landslides of any consequence to contribute to the debris carried by the water. The only occurrence approaching this phenomenon was the sloughing in of material along the gullies which resulted from undercutting the banks of these channels. In other words, all of the material carried by the floods was directly or indirectly the result of erosion of the surface by running water. The saturation of the soil to a considerable depth on steep slopes, which is usually necessary for the earth slide phenomenon, did not occur in connection with the Davis County floods. The rain which caused the floods fell so rapidly that with the surface conditions which existed on poorly vegetated areas most of the water rushed down the slopes and comparatively little was absorbed by the soil.

Causal Factors Contributing to Floods

Conditions on the Wasatch mountain front in Davis County are especially conducive to destructive floods. There are three main factors which contribute to the frequency and severity of the floods as follows:

1. The heavy rainfall of summer storms. Many of these storms which come from the southwest over the little obstructed surface of the deserts of the Great Basin, on approaching the high Wasatch scarp, are caused to rise suddenly. This rising quickly cools the moisture laden air creating a meteorological condition favoring unusually heavy precipitation. Weather records indicate that the storms causing the 1930 floods were really extraordinarily heavy storms, though rains of equal intensity may be expected at fairly frequent but irregular intervals.

2. The topography of the Davis County watershed is such as to encourage floods. The fault scarp, exposed in comparatively recent geological times, has not had time to be reduced to gentle slopes. The steep slopes and the short ravine-like canyons are highly favorable for rapid run-off. The geologic materials themselves offer large opportunities for a deluge of earth debris.

3. Vegetation, never over-plentiful, now has been seriously depleted on fair sized areas, and some are almost bare, affording conditions that permitted compounding of run-off rills into great torrents.

These three factors—rainfall, topography and plant cover, each contributing to flood phenomena—justify consideration in some detail.
FIG. 9.—General view at head of Parrish Canyon. The "light spots" are practically bare and the undergrowth in the aspen woods has been so completely destroyed that it offers little resistance to runoff. Years ago a fire swept over much of this area, destroying patches of timber. This was formerly a highly productive piece of range but is now extremely heavily overgrazed and almost completely denuded in spots.
Insofar as it can be ascertained, rainfall which was the immediate cause of the floods was rather unusual in that a comparatively large volume of water fell during a relatively short period in each storm.

In considering rainfall it is necessary to take into account the rate of fall as well as the total amount during a given storm. Investigations show, for example, that a fall of an inch in 12 to 20 minutes will cause far more surface run-off than twice that amount of rain fairly evenly distributed over a period several hours long. Rainfall records on the watersheds where the floods originated are lacking and the only data available are those from nearby stations. The only places of record of rate of fall in the vicinity of Davis County are at Salt Lake City, and for a somewhat shorter period at High Line on City Creek.

The amount of rainfall during 24-hour periods at various stations near which some of the floods occurred in 1930 are shown in Table 1.

### Table 1. Amounts of Rainfall on Given Flood Days at Various Record Stations in the Vicinity of Flooded Watersheds, 1930

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<th>Place</th>
<th>July 10</th>
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<th>Aug. 11</th>
<th>Aug. 12</th>
<th>Aug. 13</th>
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*Rain that caused flood of September 4th fell in the evening and probably was measured on the 5th at many of the stations.

Weather Bureau records show that the storm of August 13, 1923 at Salt Lake City was the most intensive one ever recorded at that station since records on the rate of rainfall were started in 1893. During that storm 0.35 inch fell the first five minutes of the storm, 0.56 inch in the first 10 minutes, 0.76 inch the first 15 minutes, 1.05 inches in 30 minutes and 1.17 inches in 60 minutes.

During the storm of July 10, 1930 at Salt Lake City, 0.22 inch fell in 15 minutes and 0.33 inch in 30 minutes with a total of 0.35 inch
during the entire downpour. On August 2 the total of the main storm in Salt Lake City was 0.35 inch, of which 0.20 inch fell in five minutes and 0.29 inch in 10 minutes, while at Air Port, only a few miles distant, a total of 1.72 inches was reported to have fallen in 40 minutes. It will be recalled that the storm of August 2 caused the first flood at Beck’s Hot Springs but only little flooding elsewhere. On August 11 a total of 1.72 inches fell in Ogden of which 0.74 inch fell in 19 minutes with a maximum of 0.40 inch in 9 minutes.

Whether or not the rainfall on the areas where the Davis County floods originated was heavier than that at the stations for which measurements are shown is problematic. However, judging by the number and depth of gullies cut under approximately equal surface conditions, the rainfall during the several storms on the mountain watersheds east of the Farmington-Centerville section probably was not heavier than the rain which caused the first flood at the north edge of Salt Lake City on August 2, which storm varied from 1.72 inches at Air Port to 0.76 inch at High Line on City Creek, more than twice as heavy in the valley as on City Creek. There was no marked indication of greater run-off on July 10 from like surface conditions on the watersheds in Davis County and the area along the front of the mountain between Parley’s and Emigration Canyons. The rainfall in the vicinity of the latter area was 0.67 inch at Lower Mill Creek, 0.60 inch at Mountain Dell, 1.03 inches at High Line and 0.35 inch on top of the Boston Building in Salt Lake City.

Storms as heavy as those causing the 1930 floods are infrequent to the extent that they do not occur, on the average, more often than once in several years to several decades. Nevertheless, the fact should not be overlooked that such storms occurred only seven years apart, in 1923 and 1930, and four times during the summer of 1930, in Davis County. Furthermore, the number of floods that have been experienced in Utah during the past 10 years alone indicate that rainfall adequate in quantity and rate of fall to cause floods from areas with steep slopes and thin vegetation may be expected in any year and at rather short intervals.

The possibility of a rather high frequency of rains of flood potential is further borne out by investigations at the Great Basin Experiment Station, east of Ephraim, Utah.

Actual measurements at that Station from 1915 to 1929, inclusive, of surface run-off and erosion from summer rains storms on an experimental watershed on high mountain lands, under conditions of exposure and elevations similar to the watersheds in Davis County, show that fairly rapid to very rapid rainfall of 0.50 inch or more causes surface run-off of flood proportions on mountain slopes that have been heavily depleted of vegetation. During the 15-year period, six storms with over 0.50 inch of precipitation have occurred which resulted in no surface run-off, 12 such storms with minor surface run-off, eight storms of from 0.52 inch to 1.36 inches of precipitation resulting in fairly heavy run-off and three storms of 0.55, 0.73 and 0.90 inch of rainfall causing very heavy run-off.
The degree of flooding from like quantities of rainfall varied with the rate of fall, having been greater for the more intensive storms. The rainfall of the last three storms approached in both volume and rate, the heavier storms recorded in Salt Lake City. During the storm of 0.90 inch which occurred on August 13, 1923, 0.53 inch fell in 15 minutes with a lighter fall during the subsequent 25 minutes. This storm had been preceded a few hours by a rainfall of 0.36 inch making a total of 1.26 inches during the day as compared to 1.23 inches on the same day at Salt Lake City.

Topography and Earth Materials

The Wasatch Mountain front facing Great Salt Lake in Davis County is an abrupt slope with steep, short canyons which greatly encourage sudden rapid surface run-off from rapid downpours of rain. The canyons down which floods came have their heads at or near the summit of the Wasatch Range at approximately 9,000 feet elevation. In a distance of approximately four miles these canyons drop to 4,500 feet or slightly lower. Each canyon is narrow and steep to within a mile of the summit where it ends in a small, somewhat widened drainage basin. Many of the slopes along the canyon sides
are very steep, that is, up to about 35 degrees. In the upper drainage basins the slopes as a rule are more gentle, in some places as low as 4 to 10 degrees.

In the main, there is little exposed rock, the watershed being largely well covered with rocky, sandy loam soils. These soils are comparatively loose and erode with moderate ease. Near the mouths of the canyons are the loose sands and gravels of the Bonneville deltas. These deltas were cut deeply and the resulting banks caved during the floods of 1930. In some cases the floods left newly exposed banks having a height of 40 to 80 or even 100 feet. Great quantities of the debris that covered the land in front of the canyons came from these unconsolidated Bonneville deposits. The fresh gullies, many of which in the head of each canyon were from 10 to 20 feet deep, also furnished from near the mountain crest immense quantities of loose earth, sand, gravel and stones as did also the canyon bottoms themselves. Altogether the steep topography and the great quantities of unconsolidated materials from the Bonneville deposits and from the slopes higher up set the stage in no uncertain way for a heavy detrital outwash where the plant cover conditions were such as to permit a heavy run-off when a summer deluge broke on the west face of the watershed.

There is at present no known way of changing the unfavorable meteorological conditions, or of modifying in any important way the topographical and geological setting. The plant cover is the only one of the three factors contributing to floods over which man can hope to exercise any control of consequence.

PLANT COVER

The slopes of the main canyons and the mountain front, for the most part, are covered with dense brush, chiefly oak. Occasional patches of timber remain on some of the north slopes. This cover generally is fairly dense with a fair depth of plant litter on the surface of the soil.

The vegetation in the basins at the heads of the canyons is variable. On the south slopes dense stands or thickets of little grazed "chaparral" brush predominate. The north slopes and the basin bottoms have open to dense stands of aspen, sagebrush and brush patches of chokecherry, snowberry and other shrubs, but with little or no undercover or litter immediately at the surface of the ground. The higher ridges are either almost barren or support only scrubby stands of sagebrush. There are also considerable areas of practically barren watershed having only a scattered stand of shrubs, or of niggerhead, lupine and other weeds. It is quite apparent, judging by the character of the site, by remnants of certain species and by the vegetation that similar sites support elsewhere, that the areas now depleted formerly had a much heavier stand of grasses, weeds, snowberry and other shrubs. The bottoms of the high drainage basins originally varied from willow swamps in the lower, wetter sites to open aspen groves with a fairly dense undergrowth of grasses,
weeds and browse. All of the present sagebrush, mixed brush and aspen cover, except the very dense stands of aspen, originally bore a good undercover of herbs and low shrubs.

Relation of Cover to Run-off

A very impressive feature was the contrast of the large and sudden run-off that had occurred on the areas having a scant undercover of vegetation as compared to those having a fairly dense undergrowth or vegetable litter. Sudden torrential run-off on soil-covered slopes leaves its telltale marks of sheet erosion and gullies. There were practically no such marks on the areas covered either with a fairly heavy stand of oak and chaparral brush or a mixture of grasses, weeds and shrubs, even on the steeper slopes. Yet the heavy gully erosion that had started on the small “islands” often only a few rods across that had been denuded by fire or some other agency, situated within the extensive brush types, gave ample evidence that the rainfall during the storms had been quite as heavy over the more densely vegetated brush types in the heads of the canyons as on the poorly vegetated areas where the floods originated.

By far the larger bulk of the flood came from the areas heavily depleted of vegetation in the basins at the heads of the canyons. Here the evidence of heavy run-off is very plain. The slopes were carved at close intervals with gullies a few inches to several feet in depth and width, with heavy sheet erosion in between, all of which is indicated by the accompanying figures. Some of these gullies were 18 to 25 feet deep within a relatively short distance of the mountain summit. However, interspersed between the badly denuded and eroded areas were fairly dense patches of chaparral and other shrubs on which there was little evidence of sudden heavy run-off. The fact that such patches were surrounded by, or immediately adjoined, depleted areas that were heavily eroded is at least good presumptive evidence that the rainfall was just as heavy on these well vegetated, uneroded places as on the neighboring denuded eroded areas.

Another striking feature is that the floods in Davis County came from a relatively small portion of the gross area of the watershed of each of the canyons. The basins at the head from which most of the water came comprise not more than one-fourth the total area of each watershed. Approximately one-third the area in these basins is still well vegetated and of the remaining two-thirds about one-half is only moderately depleted of vegetation while the remainder is severely depleted.

Centerville Canyon as a whole further illustrates on a large scale the connection between cover and the origin of floods. This canyon heads adjacent to Parrish Canyon and although it has a somewhat lower gradient and it may not have rained quite so heavily each time on its watershed, it has a much less depleted cover at the head than does Parrish Canyon. According to nearby residents, high water unaccompanied by mud flows, continued to
Figs. 11, 12.—Two views at the mouth of Centerville Canyon, showing heavy cover of trees and shrubs. This canyon, the headwaters of which are still fairly well vegetated, did not give off a devastating flood, although high water flowed down it for several hours after each storm. A similar cover of trees and shrubs also lined the bottoms of the devastated canyons prior to the 1923 and 1930 floods.

run for hours from Centerville Canyon after several of the rains that caused floods in Parrish Canyon, but the natural stream channel carried all of the water. On the other hand, Parrish Canyon, which has fair sized areas heavily depleted of vegetation on its watershed, had a sudden flow of water and mud that was much
higher than the flow in Centerville Canyon but lasted scarcely more than an hour each time.

City Creek is another drainage that illustrates the efficiency of cover in preventing floods. Heavy rain fell at least on parts of this drainage on July 10, and again on August 2. There was a slight rise in the stream but no flood in any tributary on July 10. A pile of tailings from an old mine tunnel in the north fork is reported to have contributed the clay which caused the turbidity of the water in City Creek for several days following this storm. The extra flow from the rainstorms in this tributary was all carried by the small culvert which passes the stream under the road just below Rotary Park. Two small mud flows crossed the road below High Line in City Creek on August 2. The water in both of these flows came from small areas of bare conglomerate rock on the north side of the canyon. The contribution from the adjacent plant covered slopes was negligible. The plant cover in City Creek also withstood the heavy rainfall of August 13, 1923 (1.15 inches) and another heavy rain in 1916 without a flood.

Examination revealed that the small floods in Emigration Canyon came largely from the badly depleted driveway which continues part way up this canyon and from the barren slopes at the mouth of the canyon. Likewise, the run-off which deposited a relatively small quantity of debris on the highway near the mouth of Parley's Canyon came from barren slopes in that locality. There was also a small quantity of wash into Mountain Dell Creek from the stock driveway which crosses this stream just above the Mountain Dell Reservoir and also from an overgrazed area near the head of this stream. There was no flood in Parley's Canyon drainage except the small ones in the few places mentioned.

Manner in Which Vegetation Influences Run-off

Consideration of the manner in which plant cover influences run-off and erosion will aid in the understanding of the place of vegetation in minimizing floods. Critical examination was made of many both denuded and undenuded areas in the localities where the floods originated. Where the vegetation was quite dense with a heavy ground cover of undergrowth and decaying leaves and other vegetable litter, as in the heavier stands of oak brush and chaparral, the soil was able to absorb and hold practically all of the rainfall and little run-off resulted. With a somewhat lesser density of cover more of the water ran off, but was discharged over a considerable period mostly as a thin sheet over the entire surface and did not concentrate into continuous streams down the slopes. Small rivulets sometimes formed and began to erode gullies, but as soon as the streamlets struck the plant clumps, the water spread in several directions, causing the velocity of the run-off to be checked and its load of sediment to be dropped. The result with such conditions was a somewhat reduced and a greatly delayed discharge of water and debris.

Beyond a certain point, depending upon the density of cover,
the vegetation was not able to distribute the run-off and it began to collect into continuous rivulets. These increased in size and velocity as the water rushed down the slopes carving gullies as it went. In other words, on a slightly obstructed or nearly unobstructed surface the water gained a high velocity and soon concentrated its volume in channels which further increased the velocity. With increased volume and velocity came greater cutting and carrying power, which added a large volume of solid material to the water. Quickly gathered from the slopes, this mass of water, mud and rocks formed the beginning of the mud flows which swept down the canyons in large heads, gathering debris and power and finally bursting upon the land at the mouths of the canyons.

Another of the great values of a plant cover and a plant litter on the surface when rain falls is that they retard the run-off until the dry top layer is moistened and is opened to percolation. The hard, tight crust on any bare soil that contains loam or silt is familiar to many. Skilled observers recognize that a bare soil which is also dry sheds water very fully until it is moistened. The fact that heavy showers come largely after protracted periods of drought tends to accentuate the value of vegetation in preventing floods. Still another consideration is that the vegetable matter on the surface keeps the soil pores open and thereby maintains a high rate of ab-
sorption, whereas on a bare soil the fine particles carried in the water soon work into the interstices of the soil and seal the surface against percolation.  

The influence of herbaceous plant cover in reducing the quantity of surface run-off and erosion from summer rains has been well demonstrated by the study at the Great Basin Experiment Station near Ephraim. During a six-year period from 1915 to 1920, inclusive, when a small watershed had only 16 per cent of a complete cover of vegetation, the average annual run-off from summer rains was 913 cubic feet of water per acre which removed an average of 134 cubic feet of sediment each year. From 1925 to 1929, inclusive, after the vegetation had increased to 40 per cent of a complete cover, the average annual run-off and sediment removal was 297 cubic feet and 19 cubic feet, respectively. When properly equated against the slight differences in rainfall during the two periods the study shows that the newly established 40 per cent cover reduced the surface run-off 64 per cent and sediment removed 54 per cent as compared to the older 16 per cent cover.

A somewhat similar study in Missouri, on land with an average slope of 3.68 per cent, and an average annual precipitation of 35.9 inches showed that over a period of six years 48.9 per cent of the rainfall ran off the surface on bare ground and only 11.6 per cent ran off on ground having a grass sod. The bare ground eroded at the rate of 34.6 tons per acre annually and the sod-covered ground at the rate of only 0.3 of a ton per annum.

Recent studies in Wisconsin show that under like conditions except as to cover, only 2.8 per cent of the precipitation ran off of forested areas, 7.2 per cent on native grass pastures and 25.6 per cent on land part time in small grain and part time in fallow.

Another recent study in Texas shows that 6.17 per cent of the precipitation ran off of land having a grass cover whereas on fallowed land 32.65 per cent ran off. Erosion on the grass land was at the rate of .026 inch in depth of soil annually and on the fallowed land .127 inch or about five times as great.

Manti Canyon in central Utah, a watershed which passed from full natural cover, through heavy depletion by overgrazing and forest fires, and back nearly to full natural cover again, affords a concrete example of flood control by revegetation. This canyon was

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badly depleted of plant cover between 1880 and 1888. Whereas floods were unknown prior to that time very serious ones occurred in 1888, 1889, 1893, 1896, 1901 and 1902. Beginning shortly prior to 1900 grazing was practically eliminated for several years and since 1909 there has been carefully regulated grazing. The depleted areas on the watershed began to improve and the heads of the canyons have been fairly vegetated since about 1912. A few less serious floods occurred from 1902 to 1910 but since that time there have been no floods of any consequence in the canyon. On August 17 and 31, 1909, after Manti Canyon had reached fair recovery, the adjoining canyons on both the north and south which were still in bad condition flooded severely. The flood in Manti Canyon on each of these dates was scarcely perceptible.

Perhaps the simplest demonstration of the influence of plant cover on run-off and erosion is had on city or town lawns where steep slopes are involved. Care always has to be exercised with a freshly prepared seed bed on such a lawn; otherwise, water either from heavy rain or artificial sprinkling soon begins to run off, at first
TORRENTIAL FLOODS IN NORTHERN UTAH, 1930

Perhaps in sheet form, but soon it gathers its volume in a few well defined gullies that are quickly formed and the result in a minituaire flood and mud flow down these gullies. Once the grass is well established, run-off causes little concern since the sod keeps the water spread out, and prevents the erosion of drainage channels, and while the water may run off if the sprinkling or rainfall is rapid and continues long enough, the run-off is more gradual, spread out and of little consequence. There were many examples of well established lawns on slopes that were intact adjoined by newly-started lawns that were deeply eroded in Salt Lake City after the summer rains of 1930.

The function of vegetation in flood prevention may be summarized as follows: The value of vegetation, timber, shrubs, grasses or weeds, in preventing floods from torrential summer rains in this region lies not in stopping a flood after it has started but in preventing the accumulation of run-off into floods. The maximum stand of vegetation, including timber that might be expected to grow in the bottoms of canyons, would check but little a flood once it had accumulated on the higher barren slopes. The plant cover to be effective must be distributed on the slopes and in the small de-
pressions where it will serve to delay and to distribute the run-off and thereby prevent the accumulation of run-off into streams of flood size.

**Causes of Depletion of Plant Cover**

There are three primary causes of depletion of the plant cover on the watersheds in Davis County and in other places in the State. Named in ascending order of importance they are (1) over-cutting of timber, (2) fire, and (3) overgrazing. Although never heavily timbered, each canyon once had more or less conifer timber on the north slopes, and in places fair-sized aspen, oak and maple. Up until a decade or two ago, settlers in the valley drew heavily upon these stands for lumber, poles, posts and fuel. Cutting was done without much thought of reproducing the stands and consequently there was considerable depletion of the conifer timber and large-sized aspen. The oak and maple have regenerated satisfactorily. Although over-cutting appreciably reduced the extent of timber cover, a fairly dense stand of brush has replaced the tree growth where the areas have not been overgrazed or burned frequently.

A large portion of the watershed has been burned over one or more times in the past 80 years. Some of these fires probably were
purposely set to clear out trails and roads and to open up dense brush areas to grazing. The others have been started accidentally or by lightning and allowed to burn themselves out. These fires have materially reduced the size of the timbered areas, and, where followed by overgrazing, have culminated in depletion of the cover on fair sized tracts formerly occupied by dense stands of brush. Where not heavily grazed subsequent to fire, the brush stands have recovered remarkably well within a few years after burning.

Overgrazing either following fire or of its own accord where fires have not run, has partly or almost completely denuded most of the now badly depleted areas. The grazing land on the watershed which is largely under private control very apparently has been utilized without regard to perpetuating the range forage crop, a practice which is unsound from the standpoint of economical range livestock production. The range has the many obvious marks of the past and present excessive over-utilization and of grazing too early in the spring. Practically all of the plants of fair, moderate and choice palatability which grew in places accessible to livestock have disappeared from the range. On portions of the area the former plants have been replaced in part by less palatable species such as sagebrush and various weeds. At the watering places on the streams, on bedgrounds, along lanes of heavier drift and on the adjoining more favorable grazing places the ground is almost bare with the exception perhaps of a few weeks early in the summer when certain annual plants which catch readily on bare soil furnish moderate cover. These, however, were found to have been mostly eaten off by the latter part of July in 1930 and the cattle and sheep running upon the range at that time, as well as later in the season, were required to eat "niggerhead," a mountain weed, and other plants which on non-overgrazed range usually are touched but little by livestock until late in the fall. In other places on account of slopes too steep for grazing, the presence of unpalatable vegetation, or brush thickets too dense for grazing the cover approaches its original density. Intermediate areas gradually fade from one condition into the other.

The overgrazing has been by both cattle and sheep. The damage by cattle has been confined more to the mountain basins and adjacent gentler slopes. Cattle do not graze heavily on the steeper slopes. Sheep overgrazing has extended the depletion to the steeper slopes wherever there was suitable vegetation. Such species as oak, chaparral and sagebrush are little palatable to livestock on summer range. This and the fact that the oak and chaparral frequently grow in thickets too dense for ready grazing account for the heavy stand of vegetation in places not burned and subsequently heavily grazed.

**GEOLOGY**

A study of the recent floods would be incomplete without an investigation of both the ancient and the recent deposits in which are recorded the streams' activities in the past. In the Centerville-
Figs. 17, 18.—Detailed and general views of erosion at head of Bear Canyon, August, 1930. Starting on a low gradient at the main divide, the waters gathered on an overgrazed and partially burned area and within about 150 yards washed a gully some 15 feet deep and 20 feet wide on the steep slope below.

Farmington section these deposits constitute part of the very narrow plain between the Wasatch Mountains and Great Salt Lake. The amount of material there deposited is conspicuously small in com-
parison with that of other areas in the Great Basin which is noted for its extensive alluvial fans, often miles in length, and in many cases including flood materials. In contrast, the lake comes within two miles of the mountain front in the Centerville-Farmington section, and this narrow strip is made up for the most part of deltas and other lake deposits. Special study has been given to the geology of these lake deposits, the findings of which are here briefly reviewed.

Faulting, which began in the geologic period known as Tertiary, created the Wasatch Mountains with their steep front and with the valley to the west. Accompanying and subsequent to the faulting, through millions of years the canyons were slowly excavated by stream action. The excavated material was deposited in great alluvial fans at the mouths of the canyons. This mass of valley fill was lowered in elevation by additional faulting of less magnitude before the time of Lake Bonneville. This, together with the small amount of post-Bonneville deposition, accounts for the close proximity of the present lake to the mountain front.

During the advent of Lake Bonneville, the mountain streams encountered the lake in their paths and deposited their detritus in the still water. Repeated depositions at the same water level produce a delta, which in structure and surface outline is greatly different from the alluvial fan. The alluvial fan is a sub-aerial deposit with its gradient downward becoming gradually less steep, its surface thus describing a gentle curve slightly concave upward. In contrast, the delta surface has two distinct parts: First, the material deposited just above the water's edge which resembles an alluvial fan, and second, the much steeper front which is deposited under water as the delta builds forward. The gently sloping terrace and the steeper delta front meet at an angle, which produces that abrupt break in surface outline so characteristic of deltas. The distinctive form of a delta, then, provides a ready means for identifying stream deposits made during the time of Lake Bonneville.

The greatest expanse of Lake Bonneville is marked by a distinct terrace, in some places alluvial and in other wave-cut, at an elevation of 5,080 feet in Davis County. During its recession of nearly 1,000 feet to the present Great Salt Lake, halts were made at several different levels for a sufficient time to permit the formation of distinct deltas. The lowering of the lake from the level of any given terrace gradually exposed a fresh delta front, in which the stream excavated for itself a new channel. The materials thus eroded contributed to the formation of the next lower delta. In this manner there was formed at the mouth of each canyon a series of deltas, their size and prominence depending largely on the amount of material supplied by the stream. The surface outline of such a series of deltas presents a step-like profile, which taken together with the arrangement of strata, presents unmistakable evidence of their lacustral deposition. As the deltas were exposed by the progressive dessication of the lake, the stream which constructed them became
an agent of destruction. Materials so eroded since the time of Lake Bonneville have been spread out in front at the lower levels as alluvial fans and bear no marks of deposition in still water.

These deltas, then, with their distinct profile give a basis for segregation of deposits according to the three periods of time: pre-Bonneville, Bonneville, and post-Bonneville. Such separation of erosional activity into time periods is not possible in other regions or localities where the single process of alluvial fan construction has continued without interruption through the ages. It should be kept clearly in mind that in a study of former flooding it is necessary to segregate the earlier deposits from those of the post-Bonneville period, since the latter are of chief concern. The post-Bonneville deposits represent the erosional and depositional activity that has occurred during the climatic cycle to which the present time belongs, a period variously estimated as twenty thousand years or upwards.

Well developed deltas occur at Ford Creek. The upper terraces are narrow and because of the steepness of the foothill front, the stream is deeply entrenched in them. The lower deltas are grouped more closely on a less steep gradient and have been channeled by two stream courses, whose apices are considerably below the Provo level. The deserted stream bed is known locally as "Death Hollow" and is a shallow channel extending down the middle of the deltas, while the present channel lies to the north and was long ago cut much deeper than "Death Hollow."

On the deltas are boulder deposits which are not spread over the entire surface, but are restricted to ridges of material along the margins of the old channel. These sometimes have been classed as post-Bonneville mud flows, which analysis, if correct, would substantiate the idea of at least one tremendous flood after Lake Bonneville receded. Such interpretation appears to be in error, considered in the light of several pertinent points. First, the boulders occur in a matrix of rounded materials, which indicates that they have been subjected to prolonged action of water—a distinct contrast to the angular materials of recent mud flows. Second, these boulder ridges slope gently down the terraces and more steeply down the delta fronts—in other words, they accurately conform throughout to the step-like profile of the deltas and would seem, therefore, to be a part of the delta structure. It is considered impossible for a mud flow to have passed over the series of deltas without destroying either their structure or their profile, and leave the boulder ridges conforming to and even emphasizing the delta profile. The mud flows of 1923 and 1930 filled in the low places in their paths, leaving a gently sloping top line that conforms with the profile of an alluvial fan.

On the steeper face above "Death Hollow" the stream has carved but one channel, which reaches a depth of even 150 feet. Here it is apparent that the boulder ridges which line the top of the channel's sides could not have been deposited after the stream had cut to anywhere near the present depth, but must have been deposited
Fig. 19.—Gorge at Ford Creek where the 1923 and 1930 floods added some 40 feet of new depth in previously undisturbed Bonneville sands and gravels.

Fig. 20.—Mouth of gorge at Parrish Creek showing new cutting in Bonneville sands and gravels, August 1930.

on the deltas by flood action at a time when the lake level was at the edge of the respective terraces. It seems logical that these similar boulder ridges along "Death Hollow" were constructed in the same manner as those just above it. Their common occurrence and their accurate conformity to the delta profile argue for a common origin.

The present channel through the lower deltas is much deeper
than "Death Hollow", but the process of cutting had been arrested centuries back for the gravels and sands forming the sides had long ago reached their angle of repose and a dense growth of trees and shrubs had covered both the floor and the sides. The 1923 floods ripped out the channel bottom and disclosed the delta sands and gravels which long since had been surfaced over by newer unsorted materials over which the stream had been flowing for a long time. Identification of a top layer of the 1923 mud flow fixed definitely at places along the banks the location of the pre-1923 channel, and the greatest possible depth of this channel prior to 1923 was readily ascertained by projecting normal slopes from the lateral remnants of surface fill. Actual measurements of the depth of cutting made after each of the 1930 floods show that in addition to the re-excavation of the old surface fill by the 1923 flood, the 1923 and 1930 floods together in certain places cut to a new depth of forty feet in previously undisturbed Bonneville sands and gravels. In other words, the recent floods in two seasons cut practically as deep a channel in the deposits laid down in Lake Bonneville as had been cut by previous stream action during the thousands of years since Lake Bonneville receded below the deposits. This recent cutting has occurred in spite of the fact that the normal rate of cutting becomes slower as the gradient of the stream is flattened out, and that additional work is imposed on the stream in transporting forward the ever increasing volume of fill from the longer caving sides.

Each recent flood has cut a gorge with nearly vertical sides which at once start caving and sliding, the rate of which increased rapidly after the channel surfacing had been dislodged. Fresh banks of sands and gravels have thus been exposed for the first time to a height of over a hundred feet. With the additional caving that is inevitable before these sands and gravels reach their normal angle of rest, much additional width will be added. The channel resulting will be a broad V-shape with wide flaring sides.

The post-Bonneville fan at Ford Creek is surprisingly small in extent. With the "Death Hollow" deposits terraced well out to the lake beds, there is only the fan at the mouth of the present channel to consider. The State road showed no perceptible rise at this point, and even a U. S. Geological Survey map with five foot contour intervals, though recording a notch for the stream channel, did not show the road crossing a single contour at this point. The four floods of 1930 have together added a total deposit some twelve feet in thickness at the state highway and spread out beyond the periphery of any previous fan, except for fine materials far down the stream channel. Many boulders weighing upward of ten tons were deposited on the state highway. A quarter mile below, the Bamberger Electric Railroad, constructed originally on swamp land, received a deposit of debris six feet deep that included boulders five feet in diameter. If an amount of flood material practically equal to that of this year had been added over this area at intervals of once to several times each century during the thousands of years of the post-Bonneville epoch, there would now be found large alluvial
structures extending far out into the present lake. The amount and size of materials brought down by the recent floods are all out of proportion to the rate of previous post-Bonneville deposition.

The deltas of Davis Creek also present a similar picture to Ford Creek. The boulder ridges along the high banks of the stream channel have even a more pronounced conformity to the delta profile than those at Ford Creek. Here again there is no evidence of a
tendency for the boulder deposits to obliterate the terraces or faces
of the deltas, but, as at Ford Creek, they emphasize these features.
Likewise as at Ford Creek, these boulder deposits can best be ex-
plained as having a combined stream and lake origin, rather than
having been laid down by floods after the lake reached its present
level.

Just north of Davis Creek is another group of conspicuous
boulders on both sides of the highway, which because of their position
could not have been brought through the present stream channel.
They are resting on a slope which extends back to the base of a
pronounced deltal front, in which there is no stream channel. These
boulders have been referred to as evidence of repeated flooding in
post-Bonneville time, but it is more probable that they form part
of a pre-Bonneville or Bonneville structure, the former being the more
likely. In this connection the pronounced influence on topography
of the pre-Bonneville fans and cones must not be overlooked. The
boulders and fan humps, so readily observable along the highway
and sometimes cited as proof of recurring floods since Bonneville
time, represent largely pre-Bonneville fans to which have been added
the relatively small deposits due to the normal slow erosional activity
since Lake Bonneville.

At Parrish Creek both the Bonneville and post-Bonneville deposits
are conspicuously small. The very narrow deltas and the small allu-
vial fan extend out only about fifteen hundred feet from the mouth
of the canyon where they meet the beds of the lake floor. Th's
bottom-land on which the school house stands was formerly swamp-
land through which Parrish Creek meandered. Upon drainage it be-
came highly productive land which since had been used for nurser-
ies and truck gardens. Logs of wells drilled on the area show a
depth of over fifty feet of fine material with no coarse gravels or
boulders characteristic of flood deposits. On this area the 1930 floods
destroyed houses, broke in the east wall of the schoolhouse, and de-
posited debris to a depth of several feet, including boulders of all
sizes up to twenty tons in weight. Some larger boulders were moved
down a four degree gradient about one thousand feet from the can-
yon's mouth. Several of these boulders weighed from seventy-five to
one hundred tons, and two of the larger ones were estimated to
weigh one hundred fifty tons and two hundred ten tons, respectively.

The deep gorges freshly excavated for the full length of the can-
yons which flooded are no less impressive than the flood depositions
in the valley. Cuts seventy feet or more in depth were made in
typical canyon fill consisting of materials ranging up to boulders
fifty feet in diameter. Long continuous stretches of bedrock were
exposed on the bottom of the channel. As previously discussed, the
flood waters gathered on bare and sparsely vegetated areas in the
heads of the canyons. A tributary of Ford Creek gathered waters
from the first steep slope and within a quarter mile of the summit
cut a channel twenty-five feet deep and equally wide in the gentler
slopes of a smaller basin. The exposure in this cut is all fine soil
material, with a deep humus horizon at the top, which represents
stability of the surface for centuries back. The absence of a lower humus horizon shows that the soil had not been greatly disturbed since it had accumulated. A long period of stability is indicated further by the fact that mountain maple trees up to 12 inches in diameter and Douglas fir trees up to three feet in diameter were uprooted by the flood.

Had important floods occurred frequently during the past several centuries, remnants of the old gullies more or less reclothed with vegetation would have been in evidence. No remnants of such gullies were found.

From the foregoing geological study it is concluded that the 1923 and 1930 floods mark a radical departure from the normal post-Bonneville erosion and sedimentation. In depth of cutting, in quantity of material and size of boulders carried, these floods exceed any others that have taken place since the recession of Lake Bonneville. The alluvial deposits made since Lake Bonneville's time are small, and the quantity of material brought from the canyons and added to them by the recent floods is all out of proportion to the amount brought down through the thousands of years of post-Bonneville history.

Salt Lake City, Utah
December 19, 1930.

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