GEOLOGIC ASPECTS OF TORRENTIAL FLOODS IN NORTHERN UTAH

by

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Abstract

Torrential floods of the "mud flow" type have occurred and caused considerable damage of property and loss of life, in the Farmington Section of the Wasatch Mountains of Utah. This type of flood is interpreted as being an important geologic agent, not only in the Wasatch Mountains, but in the entire Great Basin Province. They provide the means by which much of the material of the uplands is transported to the lowlands. The causes of the floods are four-fold. (1) Steep, rough topography, (2) sudden torrential rainstorms restricted to small areas, (3) filling and choking of stream channels by debris and (4) lack of vegetation.

Accompanying the mud flow floods have been periods of gullying and headward erosion, due partly to the lowering of local base levels by mud flows and partial removal of the vegetative cover.

The Federal and State governments have spent much time and money in the attempt to control these erosive and destructive geologic activities. The principle method of control has been the use of contour-trenches in the stream headwaters, designed to trap and hold back water from torrential storms. This is known as "upstream" engineering work. A supplementary method, known as "downstream" engineering works, consists in the employment and construction of catchment basins at the point where streams enter the valleys. These are designed to trap flood waters and force them to drop their loads of debris, and also to confine them within certain limits.

An analysis of the entire problem with a consideration of the time factor from a geologic, rather than humanistic standpoint is given.

Signed________________________________

Professor in charge

57 pages with 14 illustrations.

TABLE OF CONTENTS

ILLUSTRATIONS

GEOLOGIC ASPECTS OF TORRENTIAL FLOODS IN NORTHERN UTAH

INTRODUCTION

In recent years the problems of erosion and flood control have received widespread attention from many and varied groups. This is particularly true in parts of northern Utah, in the Wasatch Mountains where mud flows and floods have caused loss of life and considerable property damage. The Federal and State governments have spent large sums in attempts to protect life and property in the areas affected. Although there is a wealth of scientific literature on the general problems of flood control and prevention, the greater part of scientific research in the Wasatch area has been concerned with immediate problems as, veget-tive cover, protection from the ever present menace of floods, and such problems as affect the human beings residing in and near flood areas. The broader geologic aspects of the mud flows and floods have been, for the most part neglected, and it is the author's intention to discuss these with particular attention to the geologic history of the floods, the geologic importance of the mud flow type of erosion and a description and analysis, from a strictly geological standpoint, of the methods employed in attempting control of floods and erosion.

In presenting the various problems and considerations involved in a study of mud flows, the author will attempt to first give the reader a picture of the general geology, physiography and geography. Next a discussion as to the importance of mud flows in arid climates, followed by a history and classification of types of floods in the section to be discussed. Considerable emphasis will be placed on the characteristics, and action of mud flows, and the author will present evidence tending to show mud flows have been an important geologic process since before the presence of ancient Lake Bonneville.

The causes of mud flows will be compared and contrasted with other recent erosional activities, and in closing the author will review and present his views on the engineering methods now being employed to attempt the control of floods and excessive erosion in northern Utah.

Field Work And Acknowledgements

The author has been in close contact with the section to be discussed in the forthcoming pages since 1930. Detailed field work was done during 1936 and 1937 while the author was employed by the Wasatch National Forest.

The author is deeply indebted to Professor J.H. Mackin, of the University of Washington, for his help in the preparation of the manuscript. Also to Professors G.E. Goodspeed and H.A. Coombs, for their constructive criticisms. Thanks are also extended to the United States Forest Service for permission to use the photographs and illustrations which appear in this manuscript.

GEOGRAPHY AND GENERAL GEOLOGY

The Wasatch Mountains, lying in north central Utah, form a lofty north-south trending range, made up of twenty thousand feet of sedimentary, an unknown thickness of metamorphic rocks, in which every era and period of geologic history, excepting the Silurian, is represented. Most of the formations were deposited under marine conditions and then folded into a series of east-west anticlines and synclines. This period of diastrophism being correlated with the Laramide disturbance. These structures were subsequently truncated by the great north-south trending Wasatch fault zone, which has controlled the position and the larger part of the present day relief of the Wasatch Mountains.

The range forms the eastern boundary of the Great Basin province and rises abruptly from the basin floor, elevation 4,200 feet, to elevations as high as 11,500 feet. The downthrow to the west of the fault zone is estimated to be not less than 10,000 feet. Along the western base of the Wasatch Mountains a series of well defined shore lines record the successive levels of Lake Bonneville, which, in Pleistocene times occupied a part of the Great Basin. Three levels are well recorded, the Bonneville, 1,050, the Provo, 625, and the Stansbury, 315 feet above the level of the present Great Salt Lake. Since the disappearance of Lake Bonneville, movements recurring along the fault zone have cut and displaced the lake beaches, shore line features, and the unconsolidated materials which now fill the valley of the Great Salt Lake.

THE FARMINGTON SECTION

Introduction

The portion of the Wasatch Mountains which will receive consideration in this paper is known as the Farmington section. It is not the only area of the Wasatch Mountains in which similiar problems may be studied, but in view of the larger number of floods, and the large amount of flood prevention work done in this particular section, it serves well as a type locality.

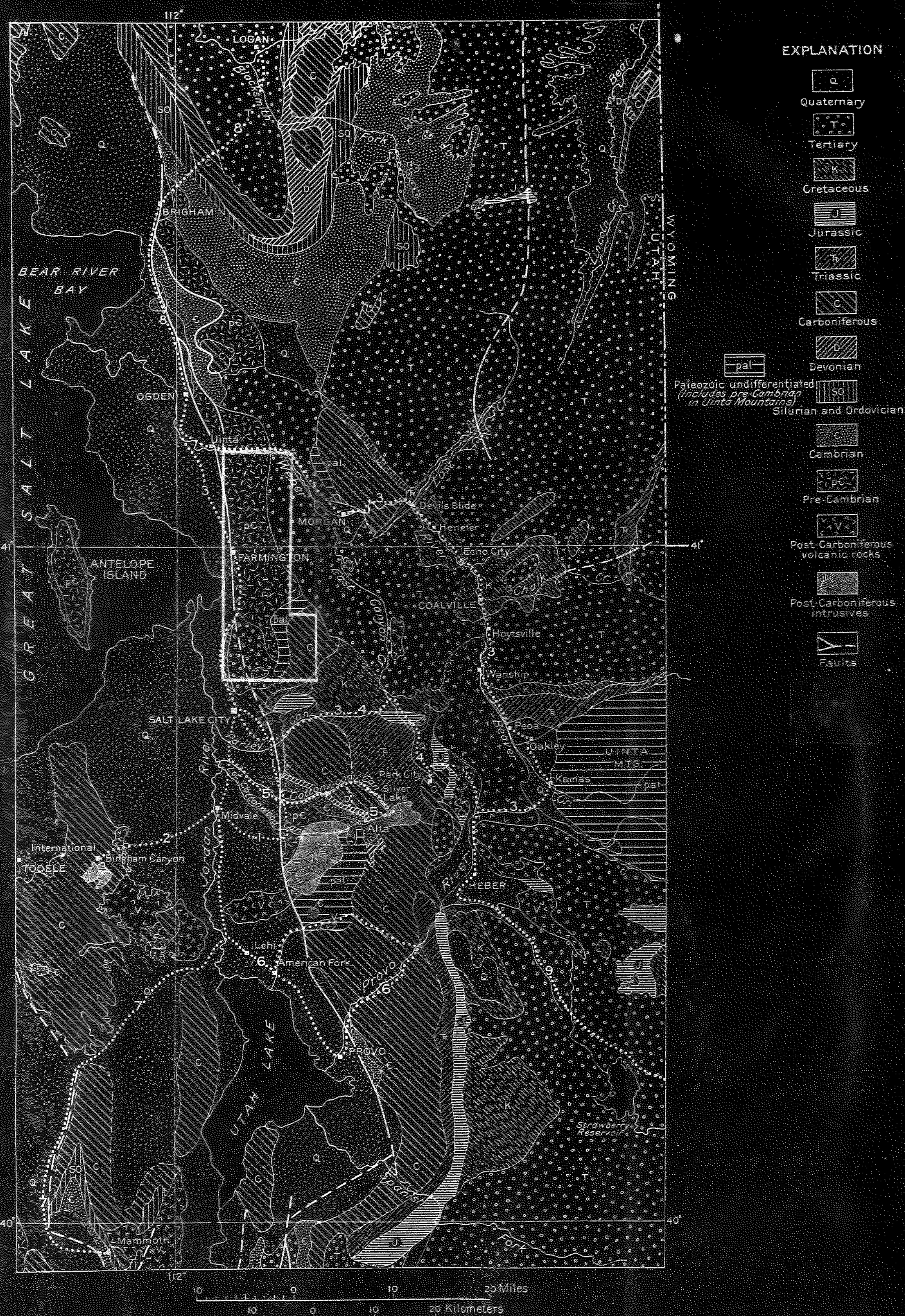
Geography--Location

The Farmington section makes up a portion of the range approximately 20 miles long, being bounded on the south by City Creek Canyon, and to the north by the Weber River Canyon. (Fig. # 1.) It is easily accessable from many points along the main Ogden-Salt Lake City Highway.

General Geology

The formations exposed in this section are Gneisses and schists, cut by a great number of pegmatite dikes. They are collectively called the "Farmington Gneiss" and are Archean in age. A small area at the southern end is made up of Paleozoic limestones and Tertiary conglomerates.

THE SALT LAKE REGION



GEOLOGIC MAP OF PART OF UTAH

From Geologic map of the United States, compiled by G. W. Stose. Shows Location of The Farmington Section

Physiography

The general physiography of the Wasatch has been well described in the work of Emmons, 1/ Gilbert, 2/ Boutwell, 3/ Hintze, 4/ and others. The Farmington section is physiographically the same as the rest of the range in its major aspects, although it is generally lower in elevation, (maximum elevation 9,500') and less rugged because of less intense glacial activity and a more homogenous bed rock. The canyons are generally shorter and steeper than in the southern part of the range. The average canyon length is about 3 miles in the northern part and 5 to 6 miles at the south. The range itself widens from 4 miles in width at the northern end of the Farmington section to about 15 miles at the southern end.

The most conspicuous features along the base of the range are the Bonneville and Provo terraces and delta deposits. The terraces are largely wave built, though some wave cut terraces are to be found. Deltas of both levels are present wherever the larger streams

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1. Emmons, S.F., "U.S. Geol. Expl. 40th. Par. Rept.:" Vol. 1, 1878
2. Gilbert, G.K., "Lake Bonneville:" U.S. Geol. Survey Mon. 1, 438 pp. 1890
3. Boutwell, J.M., "Geology and Ore Deposits of the Park City District:" U.S. Geol. Survey, Prof. Paper
4. Hintze, F.F., "A Contribution To The Geology Of The Wasatch Mts., Utah:" New York Acad. Sci. Annals, Vol. 23, pp. 85-143, 1913

issue from the mountains, and they vary in size according to the area of stream drainage and the topography upon which they were deposited. The deltas of the canyons to the north are smaller because they were deposited on steeper lake bottom slopes and by smaller streams than were those at the south. Both deltas and terraces rest upon the pre-Lake Bonneville sediments, which were in the form of alluvial fans.

Since Lake Bonneville time, the streams have incised their channels in these deltaic deposits and have formed younger deposits in the shape of alluvial fans spread out on the lower deltas and lake bottom sediments. Thus we have represented three periods of sedimentation, pre- Bonneville alluvial fans, Bonneville lake bottom and deltaic deposits, and post- Bonneville alluvial cones. The interpretation of these sediments has a very important bearing on the erosional history of the area to be discussed in connection with flood and erosion control problems.

Drainage

Drainage of the mountain block has been controlled primarily by the original block faulting and appears consequent to it. During periods of aggradation and planation the stream courses became somewhat modified, and with recurrent uplift the streams were superimposed upon the underlying structures. The streams are steep, fairly straight and but little influenced by the structure of the gneissic country rock.

The Farmington section, considered as a separate unit, is narrow and high at the north end, increasing in width, and decreasing somewhat in elevation as one goes southward. Thus the streams of the north end are short, steep, straight and typically youthfull with 'V' shaped canyons. Each stream to the south becomes more gentle in slope and mature in the stage of development, also they have greater length and more extensive tributary drainage. Mill Creek, the most southerly of the mountain streams, has cut a mature valley for about 5 miles into the mountain block and has a well developed flood plain along certain portions.

This relative difference in the stage of the erosion cycle from north to south seems best accounted for by recent and recurrent faulting along the Wasatch fault zone. The faulting, Quite possibly, may have been attended with some differential tilting of the block, with the maximum uplift at the north.

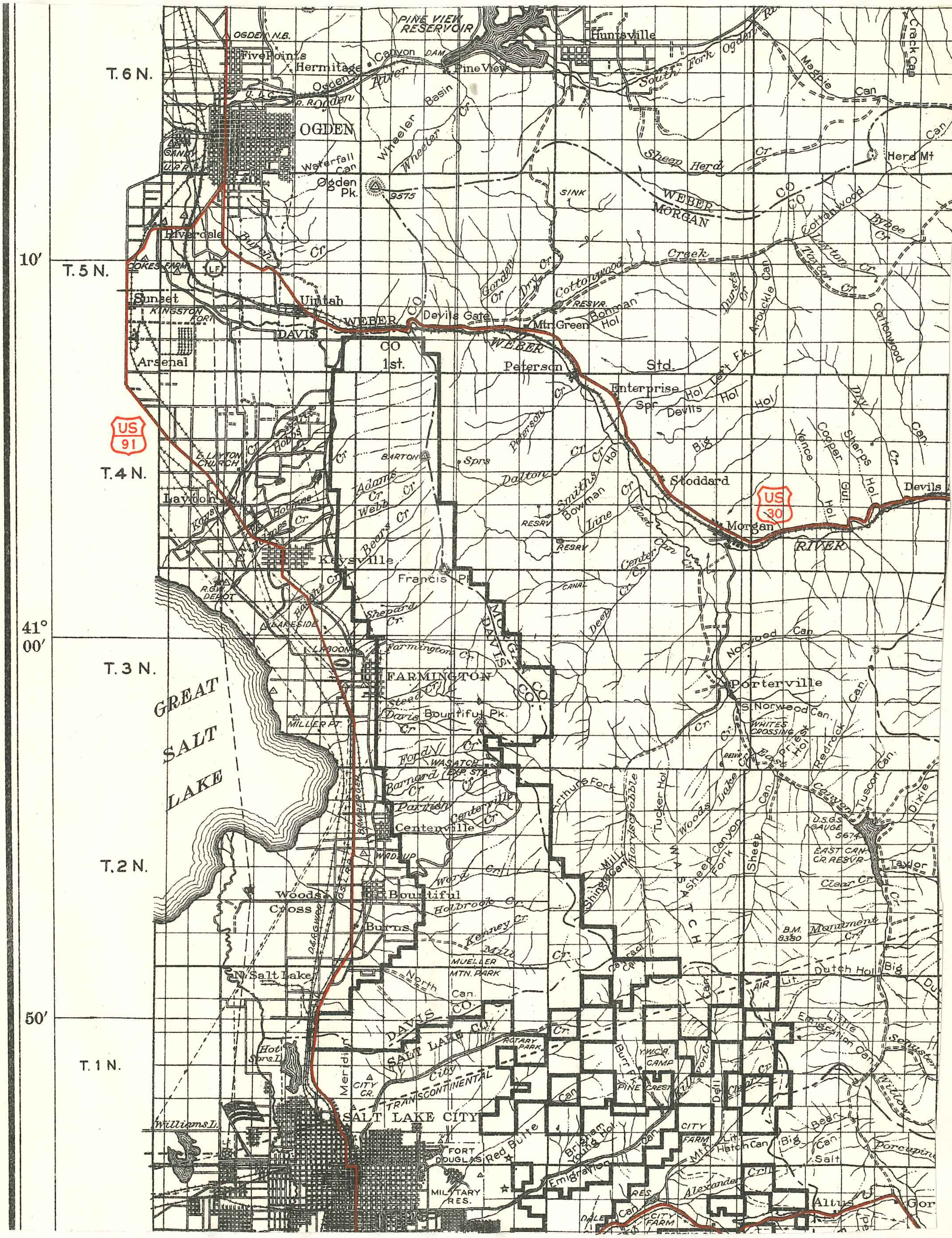

Figure # 2 Drainage Map of the Farmington Section

THE PROBLEMS OF FLOOD AND EROSION CONTROL

Torrential Floodings As A Geologic Agent In The Great Basin Province

In the Great Basin area the accumulation of wastes and debris is a slow, steady, process; its transportation is a rapid spasmodic one. That is, chemical and mechanical weathering, the accumulation of organic matter, and general surface litter may go on slowly over an indefinite number of years, then at irregular intervals, precipitation is sufficient to cause rapid removal, often in the mud flow manner, of this surface matter. This slow debris accumulation and spasmodic irregular removal from the hillsides to the valleys, is the type of geologic process now occurring in the Farmington section. There are exceptions to this kind of process in local areas where stream gradients are very low and approach base level. The removal of plant cover, or the lack of it, will cause an accentuation of the violence of the process of transportation by torrential floodings, but the presence of it will not necessarily cause a prevention of such processes. In other words, the processes of erosion will continue to be active, although the rate of activity may be influenced by a complexity of factors, and it is the author's belief that torrential floodings have long been an important part of the erosive activities of the Farmington section, and will continue to be as long as conditions of climate and topography are such as to permit continuance.

History Of Floods

The alluvial fans at the base of the range front have made very suitable agricultural areas, having tillable soils and accessible water. Settlement started near the stream banks and largely on the alluvial slopes at the canyon mouths. These areas have since served as the nuclei for the growth of population and today support about 50,000 people of the Farmington section. The alluvial fans are flood made constructional geologic features, and it is only to be expected that such areas should be visited by floods which are the agents of construction of such fans.

Settlement in the Farmington area, began shortly after the settlement of Salt Lake City in 1847 and written records of floods and high water, though somewhat meager, are to be found for years as far back as 1860. A well documented flood occurred in 1877. Written records have been supplemented to a small extent by the accounts of eye witnesses.[5/] The first serious floods to be well recorded, occurred in August of 1923 and between July, August, and September in 1930.[6/] Less destructive flows

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5. Cannon, S.Q., Chairman, "Torrential Floods In Northern Utah:" Report of the Special Flood Commission, Utah Agr. Expt. Sta. Circ., pp26-27, 1931
6. Idem p. 27

of relatively high water have occurred at intervals up to the summer of 1937. The record is not sufficiently complete to suggest definite cycles of flooding or any connection with climatic cycles.

Without exception destructive floods in the Farmington section occurred in an area extending from Ward Canyon north to the Weber River. (Fig. # 2) The significance of this will be discussed in connection with the causes of floods. Floods of 1923 occurred in Farmington, Steed, Davis, and Ford canyons. In 1930 in Parrish, Ford, Davis and Steed canyons. It is significant to note here, that while the writer has not set forth the details as to exact dates, floods did not necessarily occur in all canyons simultaneously, that is to say, a stream may flood during a storm, while its neighbor may not, and in the next storm the reverse may be the cast. This is true in the examples cited.

It is of course, important that the history of floods in this area be worked out for a period reaching far beyond the histories of mankind into the erosional history of the area, in order to arrive at a clear conception of the true nature and causes of the present day occurrences, especially as to the effect of the presence of man. In this connection, it is essential to understand the character of the floods and their action so as to properly interpret any evidence now available in the form of the deposits of the alluvial

Plate 1. Aerial view of the Parish Canyon mud flow of 1930

Plate 2. Debris left by Parish Canyon mud flow.

slope.

Briefly, these deposits consist, as stated previously,7/ of pre-Lake Bonneville sediments, alluvial fans, Bonneville deltas and terraces, and post-Bonneville alluvial fans.

Types Of Floods In The Farmington Section

At least two distinct types of floods have been known to occur in the Farmington area, (1) a more or less normal, high water stage caused by the admission to stream channels, of large amounts of water. This water may come from heavy, short summer rains, spring rains of long duration or melting snows. (2) The mud flow type of flood, which will be described in detail later.

Of the two types the mud flows are the more destructive form, from an economic standpoint, as they often deposit a thick layer of mud and rock over valuable agricultural land. Geologically they are important because they are the chief agents of construction of the alluvial fans in the Farmington section, as evidenced by the character of materials which make up the fans. Mud flows will carry materials of much greater coarseness and heterogeneity. The number of mud flows in any one canyon will be less than the number

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7. Page 4

of floods of the first type, as will be pointed out. There may be gradations between the two types of floods dependent upon the fluidity of the flood mass, but mud flows will occur only under a special combination of conditions, a detailed description of which follows.

Character Of Mud Flows

The most destructive floods are of the "mud-flow", type. Flows of this type are characterized by enormous loads of soil, debris and rock, and are of an extremely heterogenous nature.

They usually have at least two phases of action, (1) an advance flow of mud, which may or may not be preceded by a flow of high water, and (2) a high water stage.

The main mass of the mud is extremely viscous, and may be entirely dry in the frontal portions. The flow advances with abrupt side walls and front, moving along with a pushing or shoving action, coupled with a certain amount of sliding where the edges or marginal materials are fluid enough to flow. These masses have the ability to transport enormous boulders with a buoyant sort of action. (Plate # 2) The weights and size of the boulders appear to be all out of proportion to the carrying power of water, and undoubtedly is out of proportion to the carrying power of unloaded water of similar amounts.

The second phase is a high water stage of quite heavily loaded, gradually decreasing to clear water.

This high water erodes a new channel through the mud flow and deposits its load at some place below. This second phase has undoubtedly the most important erosive action, but the mud flows may be the most destructive economically, by covering agricultural lands situated on the fans where the mud flow naturally spreads out and comes to rest, probably because of lack of water and change of slope. (Plate # 1)

Very little has been written concerning the action of this type of flood. Pack[8] and Blackwelder[9] have discussed them in short papers. From these sources, accounts of eye witnesses, and personal observations in the field during and after flood occurrences, the writer has come to the following conclusions concerning them.

The activity of mud flows is not to be compared with the erosional processes of a stream in ordinary flood stage, and the interpretation of this action has an important bearing on former flood deposits which may be of a similar nature. Undoubtedly the waters causing the floods are a direct result of torrential precipitation, and rapid run-off from the watershed areas. As the flood

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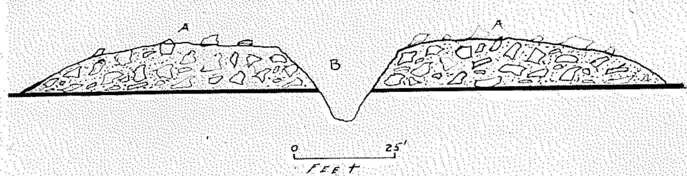
8. Pack F.J., "The Torrential Potential Of Desert Waters:" Pan. Am. Geologist, vol. 40, pp 349-356 1923.
9. Blackwelder, Eliot, "Mudflow As A Geologic Agent In Semiarid Mountains:" Geol. Soc. America, Bull., vol. 39 pp. 465-480, 1928.

waters gather in each tributary drainage and flow towards the main streams, they meet the channels of aggrading streams, which are, as a result of being choked with debris, totally incapable of handling sudden, exceptional flows of water. These channels may be full of debris, as sticks, logs, rocks, and etc., which, on being pushed together form temporary dams for the quickly gathering waters. The dams soon break through and the water continues its downward course, repeatedly being temporarily dammed. This is especially apt to occur at stream intersections, where smaller streams may have built alluvial fans. This damming process results in a concentration of water and an exceptional flow in the lower reaches of the main streams for a short period. The temporary dams are pushed along in the first surge and the following high waters are allowed to run in a more or less normal manner. It is the first surge of waters, concentrated by the damming processes, that causes the formation of mud flows. A huge load, being concentrated and picked up, until a mass of barely fluid material is advancing downstream by virtue of its own weight, or the effect of gravity plus the force and lubricating power of the water behing it. This mass may be of great enough volume to completely fill the old channel and even overflow it, it may also disregard minor curves and bends of the old channel riding directly over them. That it does much vertical cutting after reaching the mud flow stage is evidenced by the fact that where mud flows have crossed paved highways and other hard surfaces they have merely scratched and grooved. However the waters of the second phase have cut completely down through them in incising deep channels. (Fig. # 3)



Ideal Section of Mud Flow Crossing Concrete Highway
A ~ Mud Flow B ~ Channel cut by 2nd. Phase of Flooding

Figure # 3

As the mud flow reaches the gentler slopes at the base of the mountains, the force necessary to carry the load forward is dissipated and the mud spreads and stops. This loss of force may be partly accounted for by loss of water which has seeped into the unconsolidated fans. The amount of spreading may be exceptionally small, due of course, to the viscosity of the mass. In coming this far, the flow will have usually completely obliterated the old channel of the alluvial fan, and a new channel, which may or may not coincide with the old one, will be cut by the waters of the second phase of flooding. On the other hand, this obliteration will only be a covering up and not obliteration by ripping out of previously existing structures. Large mud flows on reaching the deltas of ancient Lake Bonneville may, on filling the stream channels, overflow and cover the surface of the deltas with a superficial layer of flood debris. This layer will conform to the old topography of the material on which it has been laid. If such a filling does occur, the second phase of flooding will erode a channel, leaving ridges of this flood material along the banks.

The mud flow which finally comes to rest on the alluvial fan, remains as an extremely heterogenous mass, with no sign of stratification of sorting, and makes for a rough rocky topography.

It may be said of a stream in flood stage, that is, a stream not complicated by the type of flood action described above, that there is a scour of the bottom proportionate to the volume of flood flow, and the materials thus set in motion are transported downstream. As the flood recedes, the bottom gradually rises and unless the discharge drops off very suddenly the bottom will be restored to the shape and elevations it had before the flood.

In the case of the mud flow type of flood, undoubtedly there is some scour of the bottom, particularly, in the stream heads where water is gathering. However, a point of saturation is reached and the action becomes somewhat similiar to glacial movement, except that the mud more or less, tends to merely ride over the gravels of the channel bottoms. The mud flow, however, has considerable scouring action along the channel sides. The channel deepening is accomplished by the second phase of flooding and in this case the discharge may drop off very suddenly, with the result that the channel bottom is not restored to the shape and elevation it had before the flood. Therefore the local base levels of the tributary streams are lowered until such a time as the stream balance is restored. This is important because it's effects extend to the tributary drainage and may cause gullying by headward erosion.

Recent Floodings Versus Past

The studies of all workers in the Farmington section have been directed to finding the cause or causes of mud flows and one of the first questions to be dealt with is; have mud flows occurred before or, are the present day occurrences a type of geologic process new to the Farmington section? The attempt to answer this question has led to two schools of thought. (1) Those who believe mud flows are a new type of geologic process in the Farmington section and (2) those who believe mud flows have long been an important function in the erosional history of the area.

Detailed study has revealed that deposits of the mud flow type are present in many places, in, and near the Farmington section, and represent occurrences of pre-Bonneville, Bonneville, and post-Bonneville time. These deposits do not represent regular, periodic floodings, but sporadic, irregular occurrences. The amount of time between occurrences is dependent upon a multiplicity of factors to be discussed in the section dealing with the causes of mud flows. It may take thousands of years in some instances, centuries in others, and even less time in still other cases, for the conditions necessary for formation of a mud flow to arise.

Blackwelder in describing the 1923 Willard mud flow says:10/

"It seems that the Willard mud flow was a rare but normal occurrence. The conditions observed in the canyons suggest that at any one locality two such events may be separated by centuries of time, during which the soil covering, talus slopes, and vegetation are regenerated. Similar mudflow deposits may be recognized on the alluvial fans of the Wasatch and many of the other higher and steeper mountain ranges of the Great Basin.

At the time of my first visit to the canyon, in 1909, it was an ordinary "V" shaped mountain canyon, whose sides

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10. Idem. p 470

were graded at angles of from 30--35 degrees and were covered with soil or rock waste, which was slowly creeping down the slope. This material was more or less securely held in place by a mass of grass herbage, and sheubbery and by scattered groves of trees."

Workers of the first school of thought have accepted the evidence as proof of earlier mud flows, but have interpreted all of them as being Bonneville or pre-Bonneville in age. This, in itself is inessential, as it does not alter the fact that mud flows occurred before the coming of white settlers to the area. It has led however, to a misinterpretation of some mud flow deposits which the author will discuss in order to emphasize the fact that mud flows have occurred irregularly, at least since pre-Bonneville times.

In defense of those who assign the origin of floods to abuse of the vegetative cover it must be conceded that the present day occurrences are apparently of greater magnitude, at least in size of material carried, than older deposits.

The Age Of Old Mud Flow Deposits

Bouldery material of the mud flow type may be found along the banks of present and former stream channels. Steed, Ford and Parish Creeks show such material near their channels. It must be remembered here, that stream channels have been deeply incised since earlier floods and it is not necessary to postulate floods of such magnitude as to fill the present day channels, to account for the boulder ridges deposited at some past time in the manner described on page 20.

Further evidence is to be seen in the study of both post and pre-Bonneville fans. Post-Bonneville fans, though relatively small, are present and may represent several mud flows, though as stated previously, of somewhat less coarse material than deposited by present day occurrences. It is well to remember, that in the building of these fans each deposition, while it may overlap, will not be superimposed upon the preceding one. This is mentioned because it has been argued, that since the flood of 1930 deposited 12 feet of sediment across the highway at a given point, that had floods of equal intensity occurred at intervals of 100 years, for 10 centuries, there should be 120 feet of sediments at that point, and since there is not, floods have not occurred.

Certain flood deposits lying between Farmington and Bountiful have been interpreted as part of pre-Bonneville fans because, (1) they can be followed up to a distinct deltal front, under which they do not pass, and (2) they are in such a position that no present day stream could have formed them. Close examination at the delta front does not reveal that the fans pass under, or are overlain by the delta material, but actually spread out in front. The very fact that they are recognized as fans necessitates their formation by streams from the mountain areas, and further, the fact that present day streams have incised their channels does not mean that, at some time during the past they did not have other courses, during which times they were building fans.

To summarize, floods have occurred in the past, that is prior to the floods of 1923, as shown by the historical records and the geologic evidence. In the pages to follow the writer will attempt to show that all of these floods have common, fundamental causes even though the more recent ones have an added factor of origin as is shown by their undoubted greater activity.

Recent Gullying And Headward Erosion

The period immediately preceding the last 50 to 100 years was a period of stream balance and aggradation for most of the streams of the Farmington section as evidenced by the fill of the drainage areas. In very recent times gullying and headward erosion have set in, in this bottom fill. High water stages during floods and spring run off are times of gully and channel cutting and headward erosion. These streams might be referred to then as having entered a cycle of degradational erosional activity. It should be noted that especially in the arid and semi-arid Great Basin province a stream which may be a degradational stream may actually only be so during spring run-off or periods of exceptional precipitation.

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Plate # 3. Shows recent gullying in canyon heads.

The water sheds are covered to a fair depth with a sandy soil resulting from the decomposition of the gneissic bed rodk, though certain areas of extremely steep slopes may be entirely rock outcrop.

Where soil has been able to accumulate vegetation is quite heavy, excepting for a few relatively small areas of recent depletion by overgrazing and fire. It is also true that where vegetation has started soil accumulation has been greater. In general it may be said that each drainage area is conducive to rapid run-off under certain conditions of rainfall or melting snows, and when run-off is rapid and vegetation is sparse gullying will start in.

Gullying may also start in the headwaters of drainage areas due to the lowering of local base levels. This lowering is sometimes accomplished by a mud flow in the following manner: After a stream has reached a grade, a flood occurs, and as pointed out before, floods of this type do not immediately regain their former balance, so we have a period of headward erosion and cutting until grade is again established. Once established the stream may be in a relatively balanced state until again interrupted. This is somewhat similiar to Blackwelder's ideas given on page 23. It is difficult to say how many years may elapse between such periods, but they are likely very irregular.

The Causes Of Floods And Recent Erosional Activities

Primarily the factors of any erosional activities are topography, geology, and climate. In this area the topography is right for vigorous erosion, steep and rugged, with a short, sharp drop to the drainage basin below. The geology contributes many important factors determining the type of soil or rock mantle and the flow of sub-surface waters. The bed rock of the Farmington section weathers by mechanical and chemical means to a micaceous, sandy doil which is quite porous and quite easily eroded under unprotected conditions. The compact impervous nature of the bed rock is not expecially conducive to the transportation of ground waters, and the water that does circulate within it, is largely restricted to the fissures, joints and other openings. The sandy soil, however, lends itself well to the ground water circulation and to assimilation of surface waters with the result that water percolating into the soil issues as springs in the canyon bottoms.

The climate has many important effects. It largely controls the vegetative cover, the importance of which is unquestioned. It is also a factor in the accumulation of the rock mantle. Then of course it determines the amount of precipitation and the mode of its occurrence. In this part of the Wasatch mountains and other parts of the Great Basin and Plateau provinces, where high altitudes are present, the major amount of precipitation is in the form of snow. Precipitation in the summers is of the irregular, sporadic cloudburst type. The torrential rains affect relatively small areas, but involve large volumes in a very short period of time. Temperature is extremely variable, giving rise to wide daily ranges, an important factor in the mechanical disintegration of the bed rock.

Thus we see from the above that the amount and character of erosional activity depends upon a complexity of factors. A change in any one, or combinations of which, will directly affect the cycle of erosion.

Climate

Climate does not seem to have changed profoundly since or before the times of Lake Bonneville. A slight change in the yearly precipitation could bring about the presence of the lake without materially changing the amount and types of vegetation or the character of the erosive processes. This is purely an assumption, based on the character of pre-Bonneville, Bonneville and post-Bonneville sedimentation. That rains of flood proportions may have occurred since and before these times, has already been pointed out. While records have only been kept for the last three-quarters of a century, they do not show any major departure from an average yearly climate. The records do show cycles of wet and dry years. The cycles covering from 7 to 9 years, however there is no apparent connection between these cycles and occurrences of mud flows. Figure # 4 shows the character of rainfall of flood proportions. Erratic distribution of amounts of precipitation is to be noted. According to Alter,[11] precipitation during the floods in July, 1930 was two inches greater than for any previously recorded summer storm.

Changes In Base Level

Changes in base levels of main and tributary streams have occurred and play a most important part in the development of headward erosion and gullying. Evidence for a change in base is to be seen in the recent incisions of all streams north of Centerville canyon in the fill of their channels. Local base levels of tributary streams have been lowered by the lowering of main stream channels. This lowering of base levels has changed the character of the erosion cycle to the north of Centerville Creek. To the south the drainage has suffered no recent changes in base levels.

Factors Influencing Base Level

Diastrophism of very recent age would probably be the most obvious geological phenomena to produce changes in the cycle of erosion, however there is no evidence of

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11. Alter, J.C., "Mud Floods in Utah": Monthly Weather Review, p. 319 - 320, 1930.

such action having had any recent effect on base levels.

The permanent base level of this area is the Great Salt Lake. Any changes in the level of the lake, other than minor seasonal ones, should affect all streams, however the streams which have suffered recent lowerings of base issue from the mountains at a point where the lake is very close to the mountain front. In view of this proximity, smaller changes may have some effect on drainage. Figure # 5 shows the fluctuations of the lake surface for the last ten years and consequently the permanent base level of the area's drainage. The writer has insufficient field evidence from which to form any definite conclusions and merely suggests the foregoing as a possible factor.

Changes In Stream Profiles

Floods of the type characteristic of this area remove a great deal of material from the channel bottoms and thus necessarily change the stream profile. The volume of water, which increases very rapidly to carry the material, drops off very suddenly to a volume which is minute in proportion. Therefore the channels may be a long time returning to the profile present before the floods, and as a result, local base levels are lowered with resultant headward erosion.

As stated previously those streams giving rise to

The following tabulation gives readings on the Saltair gage. The elevation of the zero of this gage is 4196.85 feet above mean sea level. Readings are for the first day of each month.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1905	0.0	0.1	0.3	0.6	0.7	0.7	0.4	- 0.1	- 0.6	- 0.9	- 1.1	- 1.0
		Readings 1906-1923 are available but not given here.										
1924	7.3	7.5	7.8	8.0	8.2	7.8	7.6	7.1	6.5	6.2	6.1	6.2
1925	6.4	6.6	6.9	7.2	7.4	7.4	7.2	7.0	6.6	6.4	6.4	6.5
1926	6.6	6.7	7.0	7.2	7.4	7.3	6.9	6.5	6.0	5.6	5.5	5.5
1927	5.6	5.7	6.0	6.4	6.5	6.6	6.3	5.9	5.2	5.0	4.9	5.1
1928	5.1	5.2	5.4	5.7	5.7	5.6	5.3	4.8	4.1	3.8	3.8	3.8
1929	4.0	4.1	4.2	4.7	5.0	5.1	4.8	4.3	3.9	3.8	3.4	3.6
1930	3.7	3.8	4.0	4.2	4.25	4.3	3.95	3.4	3.15	2.8	2.95	3.1
1931	3.2	3.25	3.55	3.5	3.45	3.3	2.7	2.3	1.75	1.15	1.1	1.0
1932	1.2	1.3	1.65	1.95	2.2	2.5	2.35	1.95	1.45	1.1	.9	.85
1933	.8	1.05	1.2	1.5	1.65	1.95	1.7	1.2	.55	.15	-.1	-.15
1934	-.1	+.15	.3	.3	.2	-.3	-.65	-1.05	-1.55	-1.9	-2.1	-1.95
1935	-1.75	-1.6	-1.35	-1.2	-1.15	-.85	-1.2	-1.75	-2.3	-2.7	-3.05	-3.0
1936	-2.9	-2.65	-2.1	-1.85	-1.4	-1.1	-1.15	-1.5	-2.1	-2.55	-2.55	-2.35
1937	-2.25	-2.05	-1.6	- .8	- .5	- .45	- .7	-1.0	-1.6	-1.95	-2.1	-2.1
1938	-1.85	-1.65										

The lowest reading of record was -3.1 feet on Nov. 15, 1935.

Figure # 5.

mud flows and floods commonly have short, steep gradients. (Fig.# 5a) Normally they are streams of small, variable flow and while they may, or not, degrade during periods of relatively heavy run-off from melting snows or summer rains, they are aggrading or at grade most of the year. During long periods of quiet much debris, in the form of sand, gravels, boulders, silt and vegetative matter, collects in the canyon bottoms. Tributary streams may form alluv-

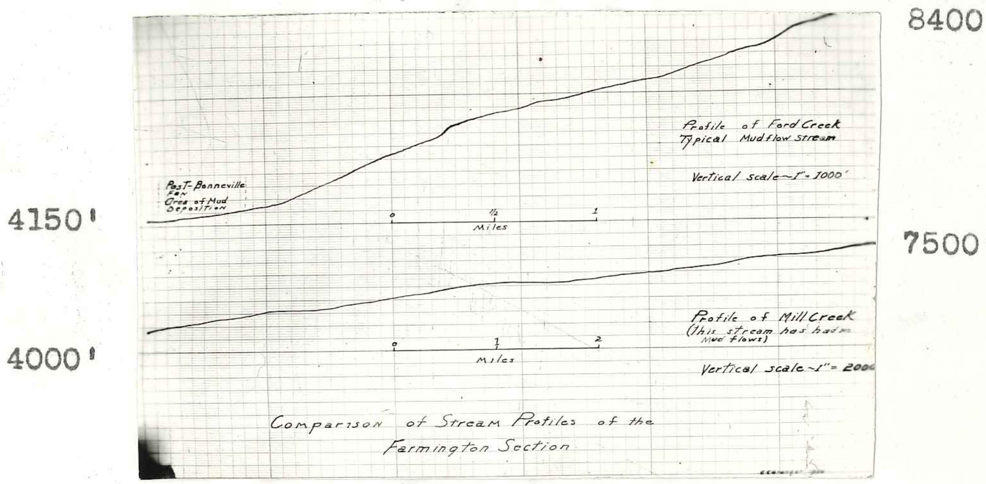

Figure # 5.a

ial fans at their intersections with main drainages and thus add to the debris of the main canyon. The fan of Whipple Creek, a tributary of Farmington Canyon, furnishes a fine example of an alluvial fan. Side slopes of tributary drainages are steep as are those of the main canyons, often reaching angles of as high as 45 degrees. Thus they shed considerable waste into the channels. This choking up of stream channels is one of the important causes of mud flows.

Depletion Of Vegetation

The depletion of the vegetative cover has an undoubted effect on local base levels as it allows rapid run-off and increased removal of waste from the slopes to the channels during times of increased water supply. This may mean aggradation in the main channels and a rejuvenation of the tributary drainage due to increased rate of run-off. The relation of rainfall to run-off has been well studied and considerable literature is available. A particularly good account is furnished by Zon.[12]

Up to twenty five percent of the areas of drainage basins has been depleted of the vegetative cover. This depletion is usually concentrated in relatively small, roughly circular areas which have been termed "Erosion Islands". (Plate # 4) Other workers in the area believe these denuded spots to be the source of generation of the mud flow type floods. They cite as proof, the fact that the gullys produced by flooding can be traced directly to these "Erosion Islands". This is based on the assumption that due to depletion of vegetation from these small areas, the run-off is so rapid as to cause floods, and the areas not depleted of vegetation hold back the water and do not contribute to the flooding.

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12. Zon, Raphael, "Forests and Water in the Light of Scientific Investigation". U.S. Dept. Agr., Forest Service, 1927.

Plate # 5. light spots are "Erosion Islands"

In contradiction to this, the cover is largely grass and according to Zon,[13] the effect of grass on run-off is practically negligible, though it does prevent removal of soil. The author believes that run-off is very nearly the same for depleted as well as covered areas, although, no doubt the depleted areas will suffer more gullying during a flood. Also an increase in the rate of run-off and soil removal will increase the rate of channel choking and filling.

In this regard the following statement was issued by the Intermountain Research and Experiment Station on November 9, 1936. The contour-trench system mentioned will be taken up in detail later.

"The specific influence of contour trenches was observed on a 150-acre tributary of Parrish Creek. On this tributary about 50 percent of the area is terraced, 45 percent has a heavy stand of vegetation, while 5 percent of the area including roads and clearings around buildings is bare.

On July 10, a rainstorm of 1.15 inches occurred over this area, of which amount .95 inch fell in the first 15 minutes of the storm. As a result of this intense storm, streamflow increased 160 times over normal, or from 0.10 to 16.00 cubic second feet for a period of about 20 minutes immediately after the storm.

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13. Idem. p 69.

Observations and measurements revealed that all of the run-off which contributed to the flash flow of the storm came from about 5 percent, or 7½ acres of the watershed, principally from cleared areas surrounding the camp buildings and from roads. No surface run-off was contributed from about 45 percent of the area on which there is a dense stand of vegetation, nor was any run-off contributed directly from the remainder or 50 percent of the watershed, which is controlled by the terrace-trench system.

On the 75 acres of controlled watershed area, however, water accumulated in the trenches in an amount that indicated surface run-off was proportionately as great between the terraces as on the roads and cleared areas around the camp buildings. Thus, it is believed that the discharge from this tributary probably would have been ten times greater--and undoubtedly would have caused a serious flood in the valley below--had it not been for the terrace-trenches which held back the surplus water."

On checking the mathematics involved in the statement, one finds that a considerable error has been made. Actually, and under the best circumstances, only 2.8 cubic second feet per minute could possibly have issued from the 7½ acres mentioned. This means that instead of the 100 percent of run-off coming from the 7½ acres as mentioned, only about 20 percent could have issued, and that the grass covered area, at least, must have contributed a sizeable amount. "Erosion Islands" are, of course, bad features but one should be cautious in assigning to them, the entire causes of floodings.

Conclusions As To The Causes Of Mud Flows

In view of the foregoing, the writer concludes that the mud flow type floods are due to the following factors; 1. topography, (steep canyons and stream gradients) 2. rainstorms of torrential quantities, falling with great rapidity. 3. Stream channels so filled with debris as to be unable to handle the sudden, exceptional proportions of water and 4. the depletion of the vegetative cover. That a depleted vegetative cover has been responsible for an increased number of floods and for floods of greater intensity, is not questioned, that floods have occurred when the vegetative cover had suffered no depletion is quite likely and probable. (This is assuming the climate and vegetation has been essentially the same since before Bonneville time and was essentially the same when earlier flood deposits were formed.) To further emphasize this statement I quote from Zon.[14] "Floods which are produced by exceptional meteorological conditions can not be prevented by forests, but without their mitigating influence

14. Idem. p 68.

the floods are more severe and destructive, further, that forests alone can not be depended upon to prevent the occurrence of exceptional floods, and that engineering works are necessary for the control of water in streams." Zon is dealing primarily with floods of more fluid character than mud flows, however, the main point, i.e.; vegetation cannot hold back sudden extreme downpours of water, is applicable to mud flow occurrences.

The Causes Of Gullying And Headward Erosion

Some gullying occurs, of course, with flooding. Gullying and headward erosion continue however, during spring run-off as well as during summer storms. During spring run-off and all periods of stream flow, gullying and headward erosion may continue, because local and general base levels seem to have been lowered, and the streams will degrade until they are in balance with the new base levels.

In general, the most important cause is lowered base levels, lowered by torrential floods and depletion of the vegetative cover. One should note here that the restoration of the vegetative cover will not stop gullying and headward erosion until a physiographical balance has been restored.

METHODS OF CONTROL

In discussing methods of control, the engineering works installed above the point where streams enter the valley will be known as upstream engineering works.

Upstream Engineering Works

The principal method now being utilized in an attempt to control and prohibit the occurrence of floods and erosion, as well as to restore the vegetative cover, is known as the contour-trench system.

Detail of the Contour-trench System.15/

"Studies show that on denuded steep slopes on the Davis County watershed as much as three-fourths of the total precipitation may run off while only one-fourth is absorbed. The contour-trench system, as developed and successfully applied here consists of a series of zero grade trenches having about 200 compartments or reservoirs per mile of trench and spaced close enough together to hold about 75% of the precipitation that falls between them. (Fig. #6 & Plate #6)

The system provides for the storage of water in small

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15. Bailey, R.W., and Cross, C.W., "Contour-trenches Control Floods and Erosion on Range Lands": U.S.Dept. Agr. E.C.W. Forestry Pub. # 4, p.4, 1937.

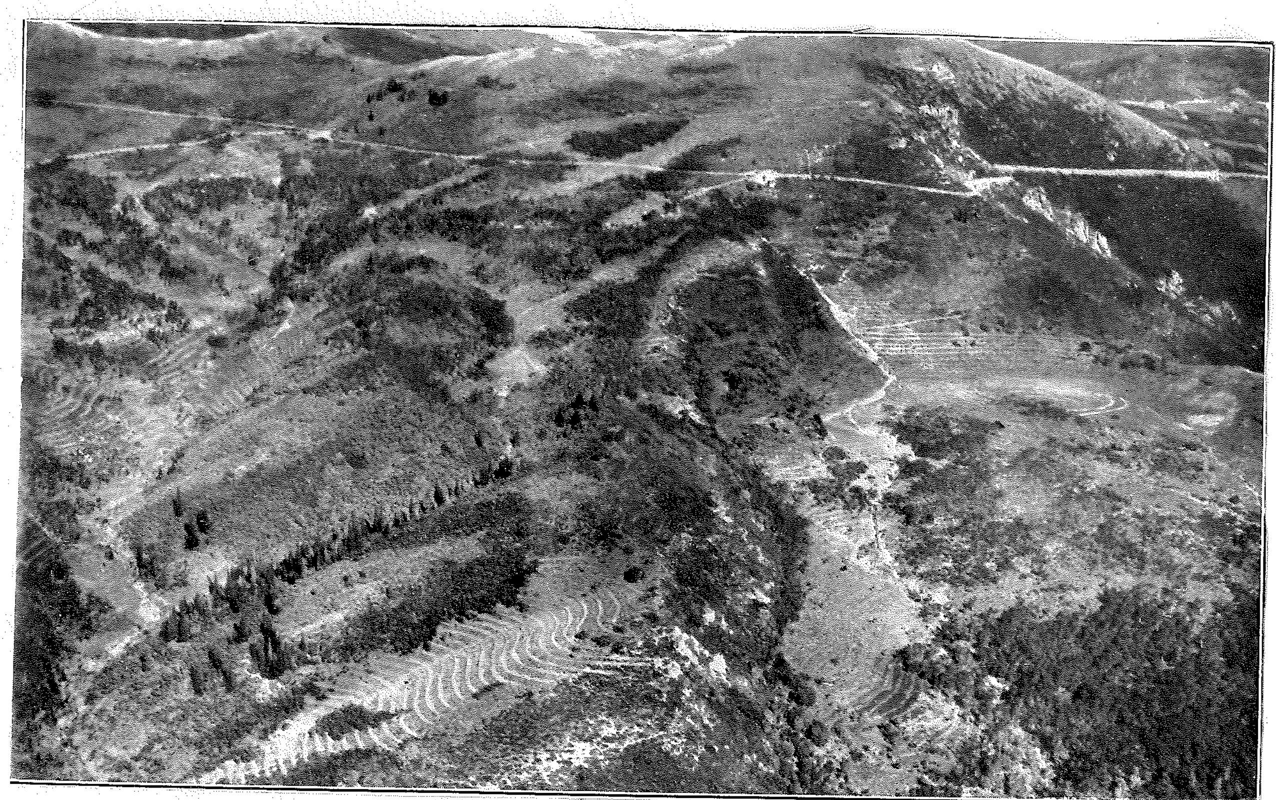


Plate # 5 Aerial View Of Contour-trenches

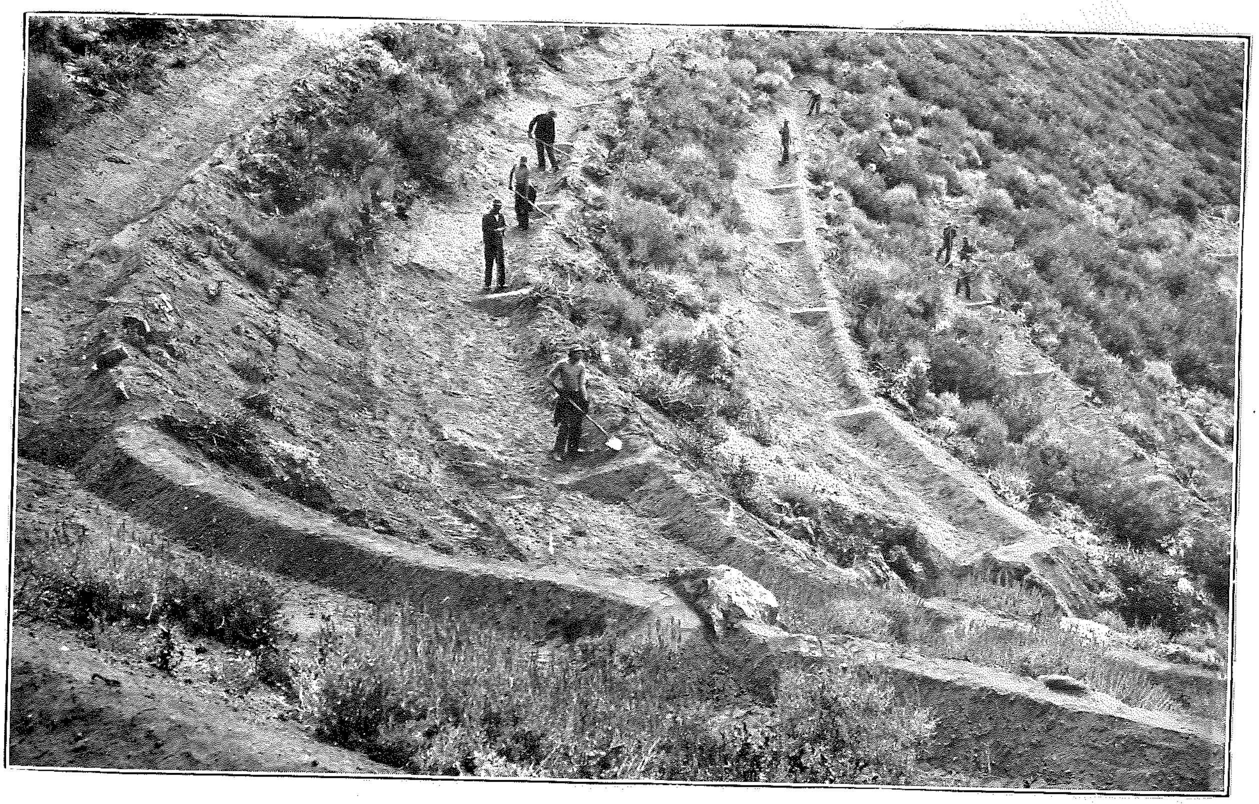


Plate # 6 Workers Finishing Contour-trenches individual units and the movement of water from one unit to another. This is accomplished by placing low cross dams, called equalizers at right angles to the trench axis at intervals of 20 to 40 fe..., so that each trench functions as a large number of small storage units rather than as one single unit. These equalizers are 0.3 foot lower than the fill dike, which allows water to flow from one section to another without overtopping the dike. This provision permits the movement of water from areas of excessive run-off such as snowbanks or small gullies, to adjacent sections of the trench where it can be absorbed. Water may also be diverted gradually along an entire trench length into rock talus, dense plant cover, or larger storage reservoirs."

Check dams in channels have been used to a small extent. No channel work in the upper reaches of the channels has been attempted.

Analysis of Contour Trenching

1. For restoring the vegetative cover on depleted areas the trenches have definitely proven themselves to be decidedly effective.

2. For controlling flash run-off from summer storms they are also effective, except that they can not cover areas of rock outcrops or areas of 60 percent, or steeper side slopes and steep terrain usually accounts for a considerable percentage of the total acreage.

3. For controlling run-off from melting snow they are also effective, however, snowdrifts of great depth and snow slides may easily damage the trenches, thus decreasing their effectiveness. (Plate # 7)

4. For controlling floods, they will be effective only if the rainfall is of such proportions that the amount of run-off from non-terraced areas is not of flood proportions. Doubtless some floods may occur in the presence of terraces by allowing water to run off such areas.

Plate # 7. Contour-trenches damaged by melting snows.

5. For inducing seepage of water into the ground they may be very efficient, as the soil is quite permeable. However, not much of the water will go into the bed-rock and hence will issue at points in gullies, basins, etc., where the water table is cut, as unloaded flows which may degrade.

6. For controlling headward erosion their use may encounter difficulties, for the drainage will be delivered at the main tributaries and master streams, free of load. If the load of tributary streams be held back the volume of the main drainages will be increased, and erosion to a flatter profile will follow. This will result in lowering of local base levels and headward erosion to compensate for it. Therefore, it is conceivable that contour-trenches might actually increase the depth, width and length of present gullies, unless check damming or some other means is employed to prevent lowering of local base levels.

7. In the construction of contour-trenches, a great deal of soil is loosened by plowing and digging, and care should be taken to prevent this material from becoming movable. Care must also be taken to prevent the reservoirs of the trenches from bursting and losing their load of water which would result in a disastrous accumulation of water and debris. Also it is not impossible that, on steep slopes with a small amount of rock mantle, the use of trenches may cause such a saturation of the rock mantle with rain waters as to cause such areas to actually slide.

8. The construction costs of contour-trenches are considerable. No official cost records considering the cost of construction roads, the maintenance of the Civilian Conservation Corps camps and expense of administrative personnel and equipment could be obtained. An estimate

based on available figures and disregarding maintenance, administration and road construction, is in excess of one hundred dollars per acre.

9. While no estimate can be made of maintenance costs, terraces must be repaired and maintained in order to insure their effectiveness.

10. The amount of area protected in the valley is very small in comparison with the area which must be terraced. This tends to make the terracing method too costly to be economic.

Conclusions as to Contour-trenches.

Conceding that contour-trenching is basically sound and feasible, it is extremely costly, and it would be interesting to be able to compare the results if in two neighboring canyons, terracing be constructed in one, and in the other check damming and channel cleaning and straightening. Prohibition of grazing and protection from fires, allowing for natural revegetation only. From the geologists point of view, it will be interesting to see as time goes by, whether or not contour-trenches will actually restore a physiographical balance and prevent further gullying, headward erosion, and the mud flow type of flood.

Downstream Engineering

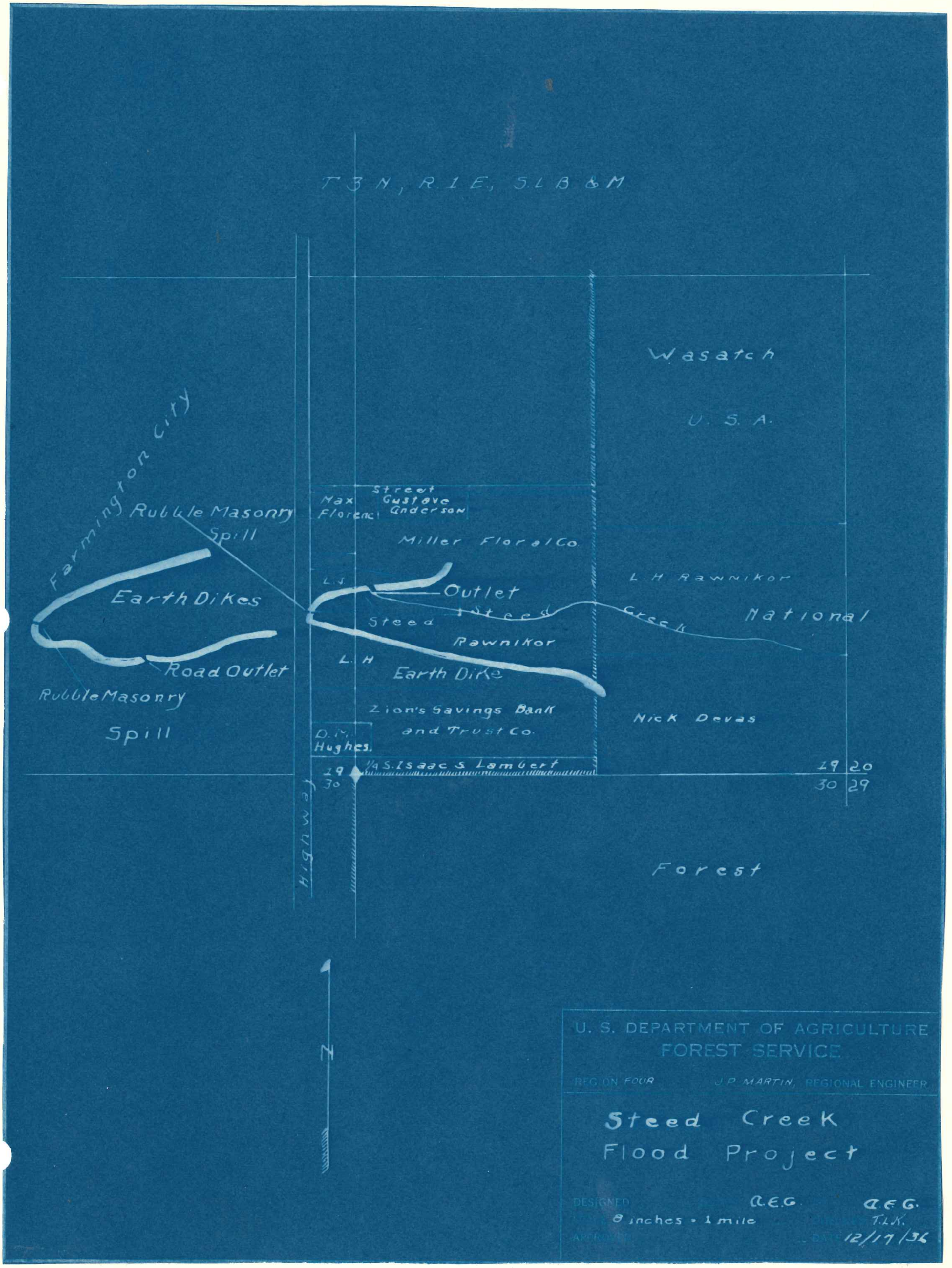
Downstream engineering works include all those installed on the fans and in stream channels below the point where streams enter the valley.

Downstream structures are mostly of the Catchment Basin type, which is simply a trap to catch the debris of floods. Constructed on the alluvial fans of the streams. They are so planned as to cause the flood waters to lower their velocity and hence drop their load of debris. Construction is largely of earth-fill work. Tractors equipped with blades or "Bulldozers", scrape dirt from the center out to the edges and form earth dikes usually about 12 feet high. For the spillways the sides are usually of rubble masonry. Figure # 7 shows the plan view of such a structure, and the following description of the project illustrated is from the files of the Wasatch National Forest.

"The project consists of two units, one above the highway and one below. The unit above the highway consists of earth dikes on the north and south which flank the mouth of the canyon with two "V" notch spillways in the lower or west dike, one at each corner, with a lighter earth dike between them. These spillways are of dry rock with a masonry shell on the face. This unit forms a debris basin for larger material.

A dip in the state highway will force flood waters into the low structures where ordinary flows are carried under the highway by two concrete pipes.

The lower unit consists of a dry rubble cemented shell


T 3 N, R 1 E, S.L.B & M
Wasatch
U. S. A.
National
Forest
Farmington City
Rubble Masonry Spill
Earth Dikes
Road Outlet
Rubble Masonry Spill
Highway
Street
Max Florence
Gustave Anderson
Miller Floral Co.
L.J.
Outlet
Steed Creek
Steed
Rawnikor
L.H.
L.H. Rawnikor
Earth Dike
Zion's Savings Bank and Trust Co.
Nick Devas
D.M. Hughes
1/4 S.
Isaac S. Lambert
29
30
29 20
30 29
N
U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
REGION FOUR
J.P. MARTIN, REGIONAL ENGINEER
Steed Creek
Flood Project
DESIGNED
A.E.G.
A.E.G.
8 inches = 1 mile
T.L.K.
APPROVED
DATE 12/17/36

spillway, 20' wide with 5' sidewalls flanked by earth dikes forming a large debris basin. The west dike contains a cemented rubble irrigation opening.

COST DATA:

The project involved the placing of about 11,600 cubic yards of earth dike, 960 cubic yards of cemented rubble work and 200 cubic yards of dry rock wall.

Costs are as follows:

Materials	$ 4,827.60
Labor	2,281.38
C.C.C. Labor	5,893.50
Total Cost	$13,002.48
Number of man days ..	3,929 "

Analysis of Catchment Basin Structures

Flood control structures of this type are undoubtedly useful, and have aided in the protection of life and property, but as employed in Davis County, they have the following disadvantages:

They must be placed quite near the foot of the fan to get low grades. This means that a flood may miss them altogether as it is difficult to guess the exact course of any flood which may issue on the fan. They are too shallow, are quickly filled up and must be rebuilt after each flood. The type of flood material with which the structure must deal does not always allow a catchment basin to hold it. Being a viscous mass it can, and has, ridden over the earthen dikes of such a structure without altering it's course to any appreciable extent. In other words a structure which will handle water at flood stage in the ordinary meaning of that term, is inadequate to cope with the peculiarities of mud flows.

Suggested Method of Control

Any downstream flood control projects are handicapped by the fact that their usefulness is but temporary, however, if they can be so constructed as to prevent the spread of mud and debris to the cultivated areas of the alluvial fans, they are definitely worth-while. The author has stated above that the type of structure now in use is questionable as to its value, and offers the following plan as an alternative.

Beginning well into the mouth of each canyon straighten, and deepen the channel, carrying the deepening and straightening down over the alluvial fans, to the marginal areas near the shore line of the Great Salt Lake. These marginal lands have no economic use and the distances involved will be less than 1 mile. (Map Fig. # 2) Construction need only consist of loose earthwork. The deepening must be of sufficient amount to hold possible floods, and to insure sufficient grade to carry the material past the fan. It is true that these channels will need periodic cleaning, but this is also true of the catchment basin structure, but at least the channel method will not necessitate the use of tillable lands as do the present structures.

CONCLUSION

Geologic processes are so immensely slow in relation to the span of human lives that it is difficult for man in general to realize their constant action. Such seems to have been the case in the area discussed in the preceding pages. When the first white settlers came to the area, less than 100 years ago, the country must have appeared essentially as it is today, geologically speaking, the alluvial fans upon which the settlers found such suitable places for agricultural pursuits, were present, as were the streams and canyons. The particular type of geologic process which produced the alluvial fans has been discussed, its erratic nature from a standpoint of time has also been discussed. To the geologist the occurrence of the more sensational phases of the process is not surprising but to the layman who has built his home on the alluvial fan it comes as a complete and unexpected surprise. Naturally he seeks an explanation and a course of action to prevent a recurrence and in doing so he is hampered by an inability to rightly conceive the time factor in geologic processes, hence he tends to lay the entire blame on something more easily understood, that is to say, he blames his fellow man. Not only the layman but scientists who deal with subjects in which the time element is more compatible to the time conception of man, as botanists, engineers, and forest and range experts, are so influenced in their beliefs. They realize, however, as do geologists, that such occurrences represent an unbalanced state in nature in an upset of the physiographical balance. An interpretation of the cause of this unbalanced state will lead to one of three conclusions.

1. That it is a man made upset, caused by overgrazing, fire and etc.

2. That it is a natural step in the geologic process.

3. A combination of one and two.

The majority of workers in the area have worked on the premise that the first conclusion is true. The author would rather accept the second and third, and quotes the following conclusions in connection with physiographical balance, and flood control structures, taken from the work of A.P. Sonderegger.[16]

"The great constructive processes of nature expressed in the functions of the vegetative cover, the stream, the alluvial fan and flood plain, combine in maintaining a physiographical balance. Any attempt to modify or reverse, these processes by flood control or conservation measures will react, in due time, in disturbing this balance. Although the effect may be slow and although it may

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16. Sonderegger, A.P., "Physiography of Watersheds and Channels": Am.Soc. Civil Eng.Trans.,vol.83,p.1120, 1919-20.

appear to a fast moving world as imperceptible, or negligible, the change of natural forces thus initiated by permanent improvements may be lasting and irresistible; hence they present new problems to solve.

Temporary structures are not advisable and are adverse to best public policy because:

A. For the physical reason than an abnormal debris load caused by failure of structures may unbalance stream activity and cause a shifting of the course of the stream, for which the agency erecting the barrier would be responsible.

B. For the psychological reason that the people assume flood control structures to be permanent and effective for any magnitude of flood. They take for granted that the natural flood channel below such works may be encroached upon and improved without risks."

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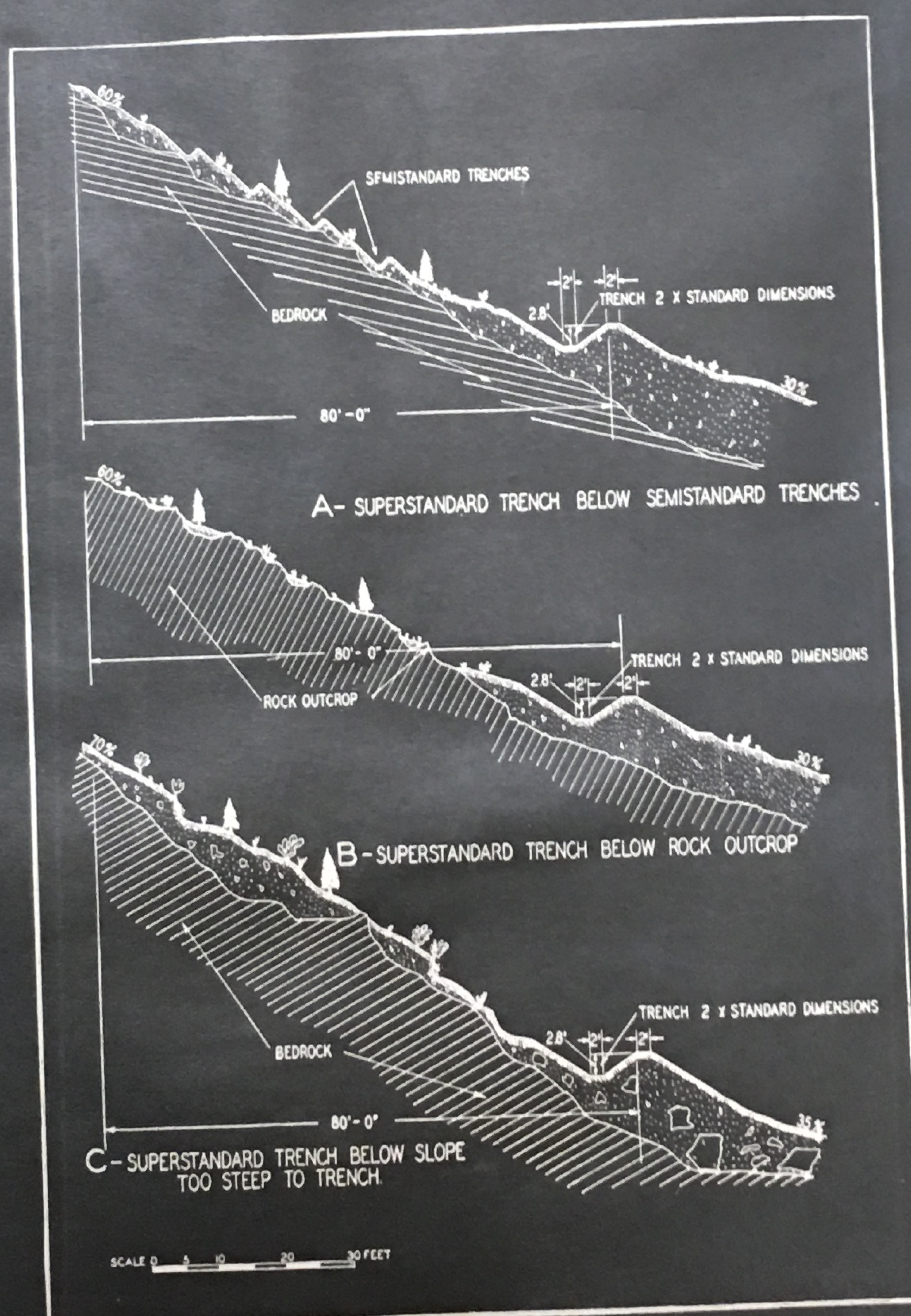
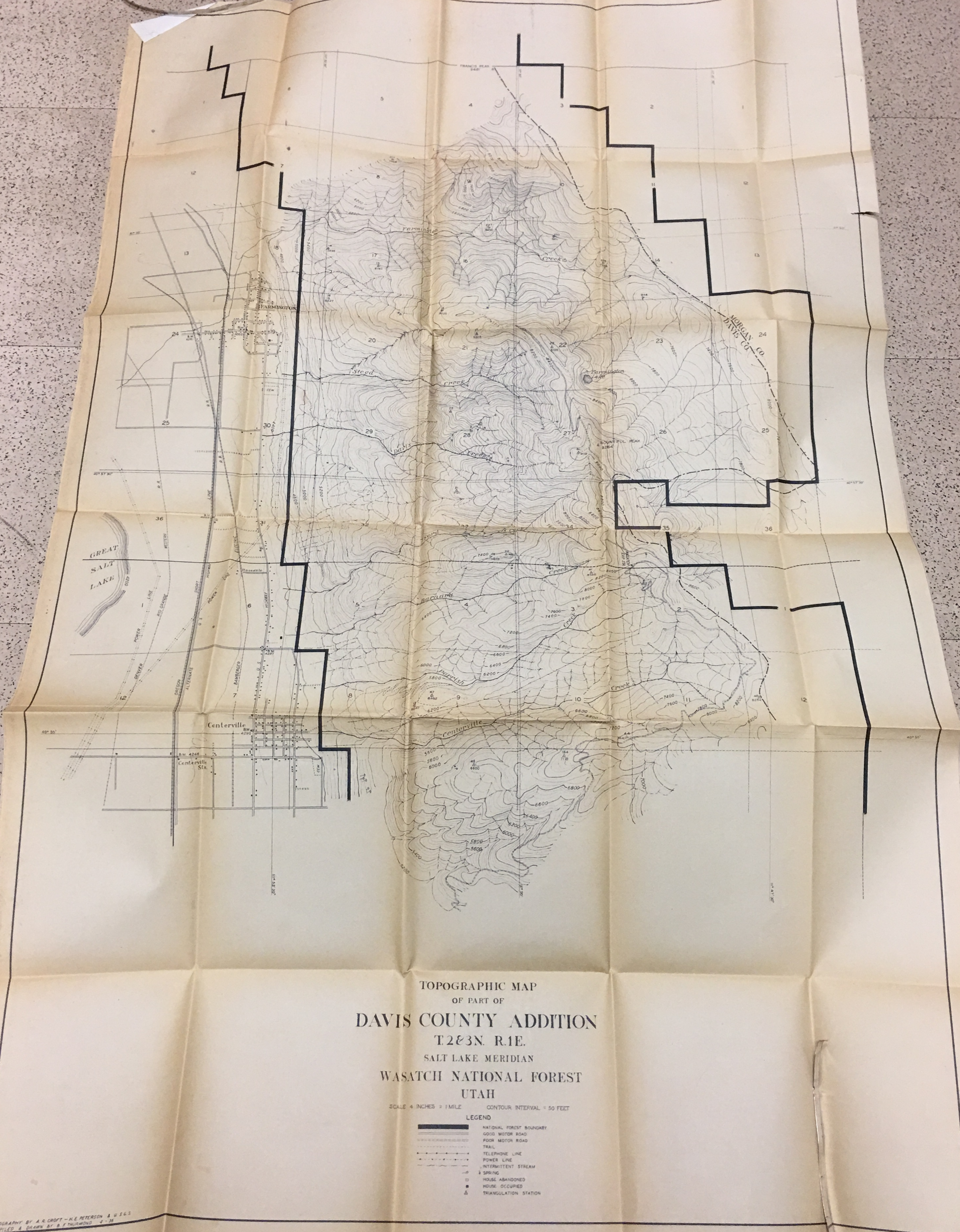


—Trench plans for special slope conditions.


TOPOGRAPHIC MAP
OF PART OF
DAVIS COUNTY ADDITION
T.2&3N. R.1E.
SALT LAKE MERIDIAN
WASATCH NATIONAL FOREST
UTAH
SCALE 4 INCHES = 1 MILE
CONTOUR INTERVAL = 50 FEET
LEGEND
NATIONAL FOREST BOUNDARY
GOOD MOTOR ROAD
POOR MOTOR ROAD
TRAIL
TELEPHONE LINE
POWER LINE
INTERMITTENT STREAM
SPRING
HOUSE ABANDONED
HOUSE OCCUPIED
TRIANGULATION STATION
TOPOGRAPHY BY A. R. CROFT – H. E. PETERSON & U.S.G.S.
COMPILED & DRAWN BY B. F. THURMOND 4 - 36
MORGAN CO.
DAVIS CO.
FARMINGTON
Centerville
Centerville Sta.
GREAT SALT LAKE
Farmington Creek
Steed Creek
Davis Creek
Barnard Creek
Parrish Creek
Centerville Creek
BOUNTIFUL PEAK