PROGRAM AND SUMMARY

COLORADO RIVER WATER FORECAST COMMITTEE
9:00 A.M. to 5:00 P.M.
April 16, 1945

STATE OF CALIFORNIA BUILDING, ROOM 1006
217 West First St., Los Angeles, California

MORNING SESSION

1. Purpose and Scope of Colorado River Water Forecast Committee, By Ralph L. Parshall, Senior Irrigation Engineer, Division of Irrigation, Soil Conservation Service, Fort Collins, Colorado. (Recorded)
   No Discussion

2. Objective and Scope of the Snow Survey Program, By W. W. McLaughlin, Chief, Division of Irrigation, Soil Conservation Service, Berkeley, California (Recorded)
   No Discussion

3. Urgency of Irrigation Water Supply Forecasts, By Ralph L. Parshall. (Recorded)
   Discussed by Mr. D.M. Baker

4. Forecast of the 1945 Runoff with Past Years Deviations, Green and Virgin Rivers, By Geo. D. Clyde, Dean of Engineering, Utah Agricultural College, Logan, Utah. (Not Recorded)
   Copy of this paper will be forwarded to the Chairman by Geo. D. Clyde.
   Discussed by Mr. McLaughlin

5. Runoff as Related to Forest Cover on the Headwaters of the Colorado River, By H. G. Wilm, Senior Silviculturist, U. S. Forest and Range Experiment Station, Colorado State College, Fort Collins. (Not Recorded)
   Copy of this paper was read by Geo. D. Clyde, then turned over to the Chairman.
   No Discussion

6. Introduction of Mr. Wm. J. Jenkins, Director of Agriculture, Bombay Province, India; Mr.
Jenkins remarks. (Recorded) Discussed by Geo.H. Cecil

7. Relation of 1945 Runoff in the Colorado River to Power Planning, By W. A. Lang, Engineer, Southern California Edison Company, Los Angeles, California. (Not Recorded) Copy of this paper was given to the Chairman

Formal discussions By (J. E. Jones, Engineer, Los Angeles Bureau of Power and Light) a/ and H. A. Lott, Operating Engineer, Southern California Edison Company. (Recorded) Discussed by Messrs. Barnes and Stanley

8. Suggestions for Improving Forecasts for the Colorado River Basin, By Frank C. Merriell, Secretary, Colorado River Water Conservation District, Grand Junction, Colorado. (Not Recorded) Read by R. A. Work, and copy then given to the Chairman. No Discussion

AFTERNOON SESSION


10. Relation of Snow Surveys and Flood Flows in California Streams, by Harold Conkling, Deputy State Engineer of California, Sacramento, California. (Recorded) Mr. Conkling will re-write paper if sent transcript. No Discussion

a/ Bradley Cozzens substituted for Mr. Jones. (Not Recorded.) Copy of Mr. Cozzens' remarks will be forwarded by him to the Chairman.

b/ Read by J. W. Stanley. Copies of both papers will be forwarded by Mr. Stanley to the Chairman.
11. The Problem of Forecasting Runoff Based Upon April 1 Snow Surveys When a Large Portion of the Snow Cover at High Elevations Occurs During the Month of May, By Dr. J. E. Church, Meteorologist, Nevada Experiment Station, Reno, Nevada. (Not Recorded) 
   Read by R. L. Parshall; copy kept by him. 
   No Discussion

12. The Importance of Snow Surveys on the Upper Colorado River Drainage as Related to the Water Supply for the Metropolitan Water District of Southern California, By Julian Hinds, Chief Engineer, Metropolitan Water District of Southern California, Los Angeles, California. (Recorded) 
   No Discussion

13. General Discussion Period. (Recorded) 
   Those participating include Messrs A. R. Work, R. L. Parshall, Bradley Cozzens, Harlowe M. Stafford and W. W. McLaughlin.
The meeting was called to order and presided over by the Chairman, Mr. Ralph L. Parshall, Senior Irrigation Engineer, Division of Irrigation, S.C.S., Fort Collins, Colorado.

(Verbatim Record Follows)

Chairman: Come to order please, gentlemen. As was announced in our program, we have a number of subjects for consideration. Therefore, it is best that we get under way as quickly as possible after nine o'clock, in order that we may have sufficient time to cover the assigned subjects. This is our first meeting of the Colorado River Water Forecast Committee. It has been a very great pleasure on my part to organize this meeting and is very gratifying to know of the fine response to the letters sent out inviting participation in the program.

We all know of the very great importance of snow as a source of water for the various uses made of this essential asset. We are to learn later today that the forests play an important part in this relation of snow and runoff in the presentation of a paper prepared by Dr. H. G. Wilm, Senior Silviculturist of the U. S. Forest and Range Experiment Station at the Colorado A and M College at Fort Collins. This paper has to do with the effect of water runoff, as related to forest cover on the headwaters of the Colorado River.
After making the statement on the back of the program, I thought I was a little conservative in my estimate that at least seventy-five per cent of the water in this stream is directly from snow. In reading Dr. Wilm's paper, I found that he had crowded that estimate up to ninety per cent. Time does not permit to refer to the several other papers to be presented today although all are worthy of special introductory comment. I am not sure that all of us actually recognize and appreciate what the snow means to the prosperity of our Western country. We can well imagine that if the Colorado river were to cease flowing, it would not be difficult to realize the seriousness of such a situation. Much then depends upon the mountain snow cover and the importance of meetings such as this, where we can discuss these various related problems with the hope of getting a better understanding of what we are trying to do, ultimately, perhaps, reaching the point where we will solve some of these more or less complex problems.

For the prosperity of the West, these problems concern our Committee. They have a number of interrelated phases dealing in a general way with; economics, engineering, meteorology, forestry, irrigation, agriculture, and many other features of the problem as a whole. We here are concerned principally from the economic standpoint, that is, planning and studying the water supply. From the irrigation standpoint our prime purpose is to forecast or to predict the water supply. For agriculture, we must predict sufficiently in advance of the season to permit of the best crop-plan programs for the farmers. Then, we have the relation of snow and water from the engineering standpoint; the construction of great works, the protection of those works, and of course, the conservation of runoff for domestic supplies, hydroelectric power
OBJECTIVE OF THE CONFERENCE

This meeting was primarily for the purpose of promoting the interest of snow surveys as related to runoff in the Colorado River for municipal, irrigation, hydroelectric and other uses. The drainage basin of the Colorado River covers 245,000 square miles in Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada and California. The melting snow cover over the mountain country of this great basin contributes at least 75 percent of the water in this stream.

Because the bulk of the water supply of the Colorado is from snow and is available for many important uses along the course of the river, this meeting was called to study and discuss some of the water problems of the river as related to snow surveys and the subsequent runoff. The excellent response in setting up this committee is very encouraging and for this reason it is quite evident that the subject of snow and water will increase in importance as more knowledge of the many problems is gained and the facts are more firmly established. At this first conference of the committee several topics have been proposed for discussion. The spread of useful information and the interchange of ideas and methods underlying the many complicated phases of the question of water and snow are expected to make a substantial contribution to the snow surveys and water supply forecasts.
and irrigation supplies. Further in this picture we see forecasts related
to meteorology, forestry, soil erosion, navigation and a host of other im-
portant parts of the problem as a whole. From the standpoint of irrigation,
we are primarily concerned with the dependence of water supplies for irrigating
and the agricultural crop production and its related industries which
upon reflection is recognized as widespread and far reaching. From the
theoretical point of view, we have consideration of all the problems in these
different fields.

So now, this morning, we are concerned with all these various subjects
which we have indicated in the program. If you have not received a program,
there is one here at the desk for you. Before I forget it, I would
like to mention that I am very pleased to find so many present at
this our first meeting. We are most grateful to you for the assistance
given in making this program worthwhile and for all the work entailed
in preparing the papers to be presented today.

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(Editors' Note: The papers presented at this meeting
are to be found arranged in sequence in the
later part of this report.)
Mr. McLaughlin: Mr. Chairman, and gentlemen. I received notice a couple of days ago that I was on this program. Between fighting for reservations—hotel, railroad and others—and at the same time trying to think of a few things I might say at this meeting it has been rather a difficult task. I am quite pleased that the length of my time has been cut into because of starting late. That pleases me, and maybe it pleases you too.

This is the question of snow surveying and forecasting of water supplies. Possibly we had better define what we mean by snow surveying. It is, in fact, the measurement of the water stored in the mountains in the form of snow and ice. When we realize that snow may have a density ranging from ten to thirty-five or forty per cent, we can see why the Department felt a need of having a measure upon which we can rely. For that reason, we defined the water content.

We use these data for the purpose of forecasting the runoff, or the yield, of water that we can expect from that snow. We do not attempt to predict the spring or the summer rainfall. In forecasting the summer precipitation, we assume we will experience a normal season. Now, what a normal season is, you know as well as I, and none of us understands it perfectly. When I think of this subject of forecasting, I am put in mind of the physician and our relation
to him. When we are well and feeling fine, we don't care where he is or what he's doing. So it is with water supply. When we have years of drought, or years of flood, our telephone rings continuously where people are wanting to know the water outlook, or what it will be.

None of us, I'm sure, will forget Pearl Harbor - how the surprise attack of the Japs almost wiped out our fleet and at the same time the emissaries of peace were in Washington talking peace. The attack was a surprise and we were totally unprepared; caught flatfooted, without forewarning of the attack. We didn't know what to expect next.

In comparison with the way the war came, we have with this snow problem the element of surprise, unpreparedness and lack of defense. Those of you who may have come from the intermountain country, or areas other than California, will recall the drought of 1934 and also 1936 — the most serious drought years in the history of man in this country. This drought, beginning in '34, extended pretty well up to 1940. There were about three-quarters of a million head of livestock shipped out of the state of North Dakota during the drought year of 1934 because there was no pasture and the hay stacks had disappeared. Here again, we had the element of surprise, or lack of warning, associated with the unfortunate feature of unpreparedness.

This occurred pretty much all over the United States, with the exception of one or two states. Utah, for instance, had a snow survey program established and three months before the drought occurred, the Governor of Utah called a conference, at which Dean Clyde, and I and many others were present. Committees were set up to form a campaign of defense and one of offense to combat the effects of the drought in the Southwest Pacific.
We weren't going to "make" rain. We didn't think of that. We were going
to tap the heretofore unused or undeveloped supplies of water. Dean Clyde and
I and others there fought the battle, when it was proposed that the Governor
declare an emergency and take over all the water supplies of the State.
That was done, and the water was distributed. What water there was, we dis-
tributed for family planting and sustenance. In Utah, we had warning of what was
to come. We were able to provide a temporary defense and therefore were not
cought entirely unprepared. In many other States they were not prepared and
therefore suffered greatly.

In connection with agriculture, and the planting of crops, the knowledge
of the expected water supply that is to prevail during the coming year will
indicate to us what proportion of early and late-maturing crops can be matured
with the water that will be available for irrigation. This will result in a
saving of money expended for seed, as well as for labor. The bank account of
the farmer will experience a saving when we have this prewarning or outlook for
the season's water supply.

Now, to summarize very briefly what has been said: We had, in the case of
Pearl Harbor, the element of surprise or no forewarning. In the drought case of
Utah, we had warning. We prepared a defense and the damage was much less than
it would have been otherwise. In the case of Pearl Harbor it was almost a killing
blow to our fleet. Two years ago this spring, our snow surveys in Idaho indicated
that the Boise Valley was in for a flood. The prospects indicated such a hazard
very pronouncedly. The Governor called a group together and prepared a defense,
by clearing the river channels. Finally, the flood came as expected and the
defense that was prepared in advance helped materially in preventing
damage throughout the Valley. Here again, we had warning. We knew what to expect. We knew the enemy's tricks and we knew when he would strike.

I think I can say that the objective of snow surveys will provide us with at least three very essential elements: (1) a pre-knowledge of the expected water supply; (2) an opportunity to prepare a defense against excess or deficient runoff; (3) an indication of the time of runoff. Therefore, in forecasting our water supplies, such knowledge is very important to the many concerned with water such as agriculture, forestry, industries of various sorts, especially mining and lumbering, the fisherman, the duck hunter, the camper, in fact to everyone who uses water. I think that takes in about all of us.

The City of Los Angeles is vitally interested in these snow surveys and much concerned in what to expect in the way of water. Likewise, the power companies, navigation interests and commercial enterprises dependent upon water, are much alive to the matter of adequate water supplies.

In the Portland area a couple of years ago, the outlook was for a very dry year. The power companies stored half a million dollars worth of coal for their standby plants. Our runoff prediction for the coming season was not entirely correct. As it turned out there was a lot of rain in the spring, an occurrence which was unpredictable and we or anyone else could not have known the amount of this precipitation to permit of adjusting the forecast upwards for that year. However, the companies told us that they would rather have had that coal in storage and not need it, than to have not had it and then need it.

I think you might be interested in a brief picture of the accomplishments of our snow survey work in the West. In 1935, the Federal Congress provided for snow surveying and irrigation water supply forecasting. That duty was assigned to the Division of Irrigation, U.S. Department of Agriculture. We were directed to
coordinate the snow surveys in the West and to assist various agencies relative to their needs for water supply information, but not to be concerned with work others wanted to pursue.

Our policy is to be helpful to the States and not to supersede them in any way. As a result, this work has moved forward smoothly and in harmony with all state, federal and other cooperating agencies. It is interchangeable, not only in this country, but with Canada as well. This snow survey project is widespread over this Western section of our country where twelve to fifteen thousand individual snow measurements are made annually by about a thousand people assisting in making these measurements. This program is highly cooperative. There are probably from one hundred to one hundred and twenty-five various agencies cooperating in carrying on this snow survey work. In Colorado there are some twenty-eight; in Oregon, about twenty-seven, etc. These cooperators are definitely interested in this work as evidenced by their moral and enthusiastic financial support. We find that instead of decreasing, the number of cooperators are increasing.

We do not have at this time full snow course coverage over this Western country, nor do we have all of the equipment we need for carrying on the work efficiently. We are fighting for a delivery of aluminum. We are buying snowmobiles, both tractor and airplane types, for travel on snow to remote localities. This equipment helps because it reduces the item of labor and cuts the time required to make these long trips. We are making progress with this work and will make still more advancement with the years to follow. We will ultimately be able to tell the people in Western Canada, in these Western United States and on down to Mexico, about what water they will have during the ensuing year for irrigation and other purposes.
There is much research work that needs to be done. Just taking a measurement of the snow depth and water content is easy, but when you get to forecasting the amount of runoff that will occur and the many other underlying factors that will change the amount of runoff, you realize the problem is not so simple. As for instance, what is the condition of the earth mantle on the watershed? How deep is it? How wet or dry is it? In the transportation of water from the melting snow, how much is going to be held back at the higher elevations? What index is the snow cover of spring in showing condition of soil moisture on the watershed?

Take the Humboldt River, in Nevada, where that Valley traverses almost the entire State. It is a rather broad, flat valley and has an immense amount of ground storage. We have here the question of how long does it take that water to drain out. In certain sections in southern Oregon there are volcanic areas where we use the snowfall of two years ago and its corresponding water content, together with the water content of one year ago and that of the past winter, as the basis for forecasting the water supply of this year. There are a lot of caverns in the lava beds and it takes months for that water to drain out to become useful stream flow.

There lies before us many problems relating to snow and water and it is the hope that as soon as things quiet down, we will be able to get at the solution of these questions. The scope of our work covers the entire West. We now have pretty well established the full coverage of snow courses on the major streams, and for the most part on the secondary streams. It is the plan to ultimately take in the minor streams, where forecasts will be useful locally in agriculture and industry.

I have attempted only to give you a brief outline of the scope of our snow survey work. If there are no questions, that is all I have to offer at this time.

Chairman: Thank you, Mr. McLoughlin. Have you some questions for the speaker? I am sure we now have a clearer conception of the scope and importance of the snow survey work in the West. This project has grown with the years and is now well established throughout these western mountains.
Our next subject has to do with the urgency of irrigation water supply forecasts. The reason for choosing this was to let you know that very shortly after the first of January we began to get letters and calls wanting to know what the water supply is going to be for the coming season. That is prior to any of our snow surveys.

For some time back, I have been attempting to find the correlation between the amount of water that comes down from the mountains as runoff in the fall, and the amount of water that might be expected the following summer. In mentioning this subject to many of my friends, I haven't been very much encouraged. Possibly they think that anyone who would set up a relation such as this, might not be altogether rightminded. Nevertheless, I think that there is something to the idea, however, it is not the thought that we can rely upon it one hundred per cent as to the accuracy of predicted flows. At this time it is only intended for the purpose of showing the trend or future prospects. If it were possible to see behind the curtain, we would be in position then to forecast accurately the immediate future. This we cannot do. The only recourse then is to set up certain relations that will guide us in visualizing this unseen picture. One of the great disturbing factors, in this premise, is the variation of the annual precipitation over the drainage basin of the particular stream and for this reason I doubt whether we will ever attain a very high degree of dependence by the use of this scheme of forecasting the runoff.

I have worked with a number of streams in Colorado and Wyoming. Some of the findings were, to my way of thinking, more or less signi-
ficant and because of the nature of the problems some were otherwise.
I want to outline briefly to you this morning some conclusions per-
taining to the Animas River in southwestern Colorado, a tributary
to the San Juan, which, in turn, is one of the main tributaries of
the Colorado River. In this study of the Animas River I have investigated
the period 1927 to 1944 inclusive and at this time will only sketch out the
general features of the problem and later to submit, as a part of the pro-
ceedings of this meeting, a more detailed report.

I have taken the runoff in acre-feet in the river for the months of
October, November and December, as measured at Durango, the sum of which
totals the factor "B". Likewise the runoff in acre-feet for the months
of April, May, June and July for the coming year, which totals the factor
"A". (Mr. Parshall explains method and constructs example on the blackboard.)
In this particular case, it just happens to work out very nicely and is
sufficiently close to show you what we have been able to do for this
one stream. When you plot these values for the years, fall flow "B",
and the coming summer flow "A", it looks something like a pattern re-
sulting from shooting a target at some distance with a shotgun. With
our work in the study of evaporation there was found this same characteristic
of apparent inconsistency. However, in the case of this runoff problem,
analysis seems to indicate certain trends and relations that make possible
the fixing of curves that point out the way to an approximate solution
of the problem. I have grouped the plotted points to agree, within
certain limits of variation to three curves, namely "P", "Q" and "R"
showing in such a diagram the relation between the acre-foot fall flow "B" and the summer flow "A". (Note: It will be noted in the paper "Urgency of Forecasting Irrigation Water Supplies", as a part of this report, that the forecast curves "P", "Q", and "R" show the relation between the October and the summer runoffs. However, a fair relation is obtained between "B" and "A".) The key or criterion to be used in the selection of the proper forecast curve has proved to be the main hurdle involved in the solution of this type of problem.

For the Colorado River study, which includes about 45 consecutive years, it will finally be found that three or four forecast curves will be necessary in the approximate solution of this particular problem. In all of the different river studies made thus far you are never sure which one of these forecast curves is the proper one to use. For the Colorado River I found a criterion that has worked fairly well which permitted the forecasting of the coming summer's flow since 1900 with a deviation of 25 per cent or less on a ratio of about 4 out of 5 years.

In considering a problem of this nature I should like to mention that my training as a statistical analyst is rather short on one end. When I began working with the problem I discussed the matter with Professor Clark, head of the mathematics department at the Colorado State College at Fort Collins and who is a specialist in statistics, informed me that in his opinion the relation of fall and summer flows was significant. It might have been if I had given him another set of data he would have found no significant relation or the flow data of still another stream might have turned out highly significant. Apparently it is one of those things about which it is difficult to tell what's what.
This rough sketch on the blackboard before you is intended only to serve as an illustration as to how I approached the problem. The paper dealing with the subject assigned to me, and to be a part of the report covering this meeting, gives more of the details of this Animas River study than does this abbreviated sketch. I have drawn for you on the board.

In summing up this subject of fall-summer relations of stream flow, as a basis of forecasting, may I say that if the problem can be worked out even within wide limits it will provide a useful tool in showing the general trend of the future water supply. If these curves and diagrams had been available early in January 1927 it would have been possible to forecast the summer runoff of the Animas River within practical limits to date for about 90 per cent of the years.

We have just issued our April first snow survey and irrigation water supply forecast reports and perhaps it would be of interest at this time to give a brief statement of the present outlook. For the North Platte and Laramie river drainages in Wyoming the coming summer runoff will be normal or better. Prospects now for adequate water supplies are very good in these areas. I read yesterday in the Salt Lake City Tribune of the heavy snow fall at Lander, Wyoming, during the past few days. This storm resulted in a depth of about 40 inches which was reported to be the heaviest in that area over the past fifty years, this snow covering the drainage of the Big Horn River. This mid-month storm will very greatly affect our forecasts made on April first. It is not unusual with us to have heavy mountain snow fall during April and even on into May or early June. The April first forecasts can be considerably at variance to the actual runoff as affected by such
a storm just mentioned. I think we could do a very creditable job of forecasting if we could depend upon a normal precipitation after our forecasts have been made.

For the Colorado River and its several tributaries in Colorado and Wyoming our snow survey data, as of the first of this month, appears to show that a normal runoff from the headwaters of these streams can be expected this year. Conditions for the Rio Grande appear to be quite promising and the season's runoff will probably exceed that of last year.

Generally speaking our forecasts have been reasonably good - at times almost in complete agreement, which of course is more or less accidental. Perhaps on the average we should not expect agreement between the forecast runoff and the actual much closer than about ten per cent.

Are there any questions or discussions?

Mr. Donald M. Baker: (Consulting Engineer, 108 West Sixth Street, Los Angeles) You mentioned the fact that there was a very decided deviation during the '30s. That was a dry period.

Chairman: Yes, generally the trend was subnormal precipitation with a corresponding deficient runoff. This was especially true for 1934 when the water supply for irrigation reached an all-time low throughout practically the entire western part of the country. The conditions existing for 1931, '34, '39 and '40, Animas River drainage, was decidedly subnormal. Our next paper is to be presented by George D. Clyde, Dean of Engineering, Utah Agricultural College at Logan. His subject is "Forecast of the 1945 Runoff with Past Years Deviations, Green and Virgin Rivers", Dean Clyde.

Dean Clyde: (Will dictate his remarks and forward to the Chairman).

Mr. McLaughlin: What proportion of the deviations is greater, and that per cent is less, than the forecasts?
Dean Clyde: As I scan through this, I see that most of our forecasts have been less than the actual. I think it is always better to prepare for less, rather than more, than you are apt to get.

Mr. McLaughlin: Is it not true that assuming your forecasts, based on normal stream flow would indicate normal precipitation, has caused most of the disturbance.

Dean Clyde: That's right.

Chairman: There being no further discussion we will turn our attention to the next paper on the program. I have asked Dean Clyde to read Dr. Wilm’s paper, entitled "Runoff as Related to Forest Cover on the Headwaters of the Colorado River". This paper should be of special interest to us at this time. Dean Clyde.

Dean Clyde: (Reads Dr. Wilm's paper)

Chairman: Are there any questions or discussions relative to this paper? We now have further appreciation of the relation of snow and the water that flows in the Colorado River. We have a very distinguished gentleman with us today. He traveled for six weeks by boat to get here. I take pleasure in introducing Mr. William J. Jenkins, Director of Agriculture, Bombay Province, India.

Mr. Jenkins: Gentlemen: I am very appreciative of the privilege of attending this meeting. I didn't expect to get down to things so quickly.

There haven't been any very great amount of snow down in our country, however, I am particularly interested in the paper, just presented. We have a very large tract of forest and we have the erosion problem which is becoming a very serious one. In our forests there is a certain amount of cultivated area which is farmed every three to five years over a period of about thirty years and then the land is allowed to revert back to the
natural yields. Some have associated the erosion with these small patches of cultivation. I would like to know if there is a dense undergrowth in the forest cover mentioned in Dr. Wilm's paper?

Mr. George H. Cecil: (Conservation Department, Los Angeles Chamber of Commerce.) I can answer that. No, there isn't a dense undergrowth.

Mr. Jenkins: I can't say anything more. I'm rather out of my realm. I would just like to say again that I am very glad to be here, and I hope I will be allowed to continue to sit in on this meeting.

Chairman: We are most happy to have you with us, Mr. Jenkins, and trust you will find it possible to be with us the rest of the day.

Sometime before we adjourn, I should like to discuss with you some of the things I have in mind, concerning the matter of forecasting for 1945. Since this is an important item to be discussed by this forecasting committee I hope it will be possible to take up this feature of our meeting sometime this afternoon. We are now moving along nicely with the program and at this time suggest we take time out for a short recess.

(ten-minute recess)

Chairman: Will you now come to order please? Our time has been spent so far this morning in getting in mind the idea of forecasting for irrigation. We will now divert our attention to the matter of power. We have asked Mr. W. A. Lang, Engineer, Southern California Edison Company of this city, to present this subject with relation to the 1945 runoff in the Colorado River as to power planning. Mr. Lang's remarks will be followed by a discussion by Mr. H. A. Lott, Southern California Edison, and Mr. Bradley Coszens, Los Angeles Bureau of Power and Light who will speak instead of Mr. Jones. Mr. Lang —
Mr. Lang:  (Reads - no record made by reporter.)

Mr. Bradley Cozzens:  (Reads - no record made by reporter.)

Chairman:  Those of us engaged in snow and water work are always looking for problems. There appears to be quite a bit to the question of finding out how much water is going to be available to turn the wheels of industry.

Mr. H. A. Lott:  After the paper by Mr. Lang and the discussion by Mr. Cozzens, you may know that there isn't much left for me to say. I thought you might be interested in the rest of the Pacific Southwest, which includes most of California, Colorado, Utah, Arizona and New Mexico. Kilowatt-hours generated in that area in a year's time have shown a remarkable advance in California. During the past years, 1941, 1942, 1943, and 1944, there were approximately four billion kilowatt-hours produced.

Boulder Power output varies according to the water supply. For a poor water year, there is generated about four and one-half billion kilowatt-hours, and for a good year about six and one-half billion. In a good year, there is some additional water spilled. The problem of a poor or a good water year is of extreme importance to the West's utilities. For instance, for a good year, when all the utilities are using hydroelectric means for generating power, they are still required to use about six or seven million barrels of oil, whereas, in a normal year, about thirteen million are required, and in a dry year it takes approximately nineteen million barrels. So, the problem of weather is important. It is of great importance to know if we will have a dry year or a wet one. If the latter is the case, then how much?
In Mr. Lang's paper the difference between the figures which are
given for the minimum and maximum water supply which might be expected
in the Colorado's in-flow to Lake Mead were, in round figures, about six
million acre-feet, which will require six million barrels of fuel oil
to displace that difference. Otherwise this six million barrels of fuel
oil could be divided between several utilities. Now, during the war period, the
fuel oil situation is critical. We will still have it after the war is over.
The electric and water people are the oil companies' best customers, but they
would probably tell you that the utilities are the most unsatisfactory
customers because their demand is not uniform due to variation of
precipitation, which in turn changes the oil requirements.

As Westerners, we are all quite optimistic and, possibly, a little
inclined to disregard some of the warnings that have come to us during the war period, namely, the fact that wealth from so many of our natural resources
have been materially restricted during the war. Fuel oil is in this
category and may be a critical item after the war. If that is the case, we will still have to program our fuel requirements quite effectively for
economical operation. The knowledge of water resources is going to
be quite an aid in the preparation of the estimated supplemental fuel
oil required to meet the constant expanding power demand.

I jotted down a thing that might occur in the future of forecasting,
when forecasts can be made ten per cent accurate. Out of a ten million
acre-feet of water supply for the year, the error might be one
million acre-feet, or in round numbers this amount in error would
generate four hundred million kilowatt-hours. That would not be
so much or so bad a problem as six million barrels of oil.

I am pleased to have the opportunity of contributing to your snow
survey conference. I am sure that so far as the Southern California Edison Company and I are concerned, we wish you every success in the cause we are so vitally interested. We need an accuracy of forecast of the Colorado River runoff that approximates that in California. We know your problem is broader because in California we get our flow mostly from rain.

Mr. Bertram S. Barnes: (Regional Engineer, 6th Region, U. S. Weather Bureau.) Mr. Lang brought up the question of correlating records of runoff. I believe that is now being undertaken in our Kansas City Office. The last I heard, they were sending for all the records of the Lower Colorado River. They are making a correlation of the type practiced in the Bureau.

We have, for the past two years, made special forecasts for the Bureau of Reclamation for the Sacramento River. These were on a somewhat similar procedure, but a more permanent one. Our correlations are mostly graphical, but starting this year, we are using mathematical correlations throughout, experimentally. This means, when we attempt the correlation, that we run into some terrific figures. That is the present order — that we carry the thing out mathematically from start to finish.

The assumption that it varies from the minimum is not nearly so erroneous, and is the best way to attempt such a clarification. We have been starting our forecasts of the Sacramento River with a January report, which is largely a guess, based upon the past twenty-five or thirty years' history. In other words, we have a probable value, based on the little information obtainable in January. We effect another, later on, assuming the precipitation after January, and another value that will be the highest value.
Our forecasts consist of three phases. The February forecast pulls the two extremes a little closer together. The most probable figure bobs up and down as the survey progresses. We are now attempting this year to put out five surveys instead of three for each one of those. The lowest figure is the one indicating that the odds are thirty to one that it will be exceeded. On the second, the odds are three to one it will be exceeded. The third is the more probable, based on up-to-date information. On the fourth, the odds are three to three it will be exceeded. The fifth the odds are four to five that it will be exceeded.

This is an interesting experiment and we, as well as a lot of other people, will be much interested in knowing how it will come out. We have a forecast for the Columbia Basin, and I think it is the first forecast of the new type survey. We are going to try to revamp our Sacramento figures to follow the new procedure.

Chairman: The further we go into this matter, the better we can see. Gentlemen, are there any further questions? Mr. Stanley: (Bureau of Reclamation, Boulder City, Nevada) I should like to ask Mr. Lang if I understood him correctly. Is the maximum deviation ten per cent, or is it the average? Mr. W. A. Lang: You mention this in connection with the forecasts of water flow in California. Generally, our forecasts fall within ten per cent plus, or ten per cent minus of the actual. Over in the Edison Company, we tried to plot the expected runoff as based on precipitation records for a number of past years. We took the November to April figures by months for precipitation at all of the stations in Colorado, Utah and Wyoming, without weighing them, and let them fall where they might. We got something like your "P" and "Q" curves and said
if the year before was a good supply year, it would be "plus". If it was a bad one, it would be indicated as "minus". Two things were wrong. The accuracy is poor and then, by the time we got all the data in and set up, the actual records were available. It was inaccurate - there were mistakes. Ninety-four point two (94.2) is the best we had, by using all the months from September to April, and that correlation has a coefficient of nineteen hundred and forty-two point two (1942.2).

Chairman: In following those diagrams, did you sense the close correlation between your precipitation and runoff curves? There was one place where it was definitely a very fine correlation.

We are now approaching the lunch hour. I am wondering if it might not be appropriate at this time to have something in mind as to what we want to consider for discussion covering the 1945 runoff. This, with the thought that while having lunch, ideas may occur to you that will be useful to the Committee during the afternoon session.

Mr. R. A. Work: Mr. Chairman: For several years, I have been associated with the work which has been carried on by the Columbia Basin Water Forecast Committee. That Committee has functioned for some nine years. They have devised a method of procedure in analyzing these records and interpreting them for application by the utility people, by the irrigation people, and by commercial firms interested in agricultural production for one reason or another. I wouldn't want to say that their procedure should be followed at this meeting, however, it might give us something on which we could target our gun.

The procedure in that Committee has been for those having the most intimate knowledge of conditions in local areas of the Columbia Basin to present their data as to snow cover and those other factors
which influence runoff — such as reservoir storage, evaporation, the
hold-over, lake effects during years of incline or decline, etc. The
current stream flow is used too, as an indication of that which is to come.
All of these things, and more, have to be considered in arriving at the
estimate of the number of gallons of fuel oil that must be procured.

Then, everyone in attendance at that meeting has the opportunity
to contribute data or ask pertinent questions. The upshot of the meeting
usually is that we come away from there with quite a precise idea of the
probable behavior and flow of the Columbia River, and the result of that
prospective flow upon agriculture and industry in that stream basin.

Therefore, the result of the Committee's consideration of these
problems is of interest to all water users throughout the Basin. Means
have been developed for acquainting the water users throughout the Basin
with the results of the Committee's study — by means of releases of perti-
nent information through the press, radio and also by means of printed reports
such as the mimeographed release you have here. If that plan were to be
followed here, I expect you would have a comprehensive summary of snow,
water, reservoir conditions covering the Upper Colorado River basin.

The same information could be had from Dean Clyde and other representatives
present for the Upper Colorado and north to Canada. Thank you.

Chairman: — Thank you, Mr. Merriell, Secretary of the
Colorado River Water Conservation District, Grand Junction, Colorado.
(Mr. Work reads paper of Frank C. Merriell, Secretary of the
Colorado River Water Conservation District, Grand Junction, Colorado.)
Chairman: — (Meeting adjourned for lunch)

AFTERNOON SESSION

Chairman: Gentlemen, you will please come to order. We were
fortunate in being able to advance the program by disposing of one of the
papers during the morning session that was listed for presentation this after-
noon. If agreeable, we will, therefore, now discuss the subject of methods...
Mr. J. L. Honnold, Engineer of the Bureau of Reclamation of the Denver office and second, a discussion on this same subject, written jointly by himself and Mr. R. E. Kennedy, who is an engineer with the Bureau at the Boulder City office. These men have done a lot of work on this subject and I am sure we will gain much from these contributions to our afternoon program.

Mr. J. W. Stanley: During the past several years, the forecasting of inflow into Lake Mead has been carried on by Mr. Honnold in the Denver office. Beginning with the year 1946, this work will be transferred to Regional Office Number 3, at Boulder City, Nevada. To that end we are working down there - trying to see what can be done to improve the precision of the forecasts.

Mr. Honnold has prepared a paper, outlining the methods they have used. I will read his paper and then will follow with a discussion covering the attack we are pursuing at the Regional Office, at Boulder City.

(Reads Mr. Honnold's paper, copy of which was given to the Chairman.)

Mr. Stanley: Over at Boulder City, we have started work in the correlation of precipitation as an element in the prediction of spring outflows. I have prepared an outline telling what we have done so far and what we hope to accomplish later on. This is made on the basis of snow surveys.
Mr. J. W. Stanley is to present two papers dealing with the runoff of the Colorado River, first, one prepared by Mr. J. L. Honnold, Engineer of the Bureau of Reclamation of the Denver office, and second, a discussion on this same subject written jointly by himself and Mr. R. E. Kennedy, who are engineers with the Bureau at the Boulder City office. These men have done a lot of work on this subject and I am sure we will gain much from these contributions to our afternoon program.

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(Reads Mr. Honnold's paper, copy of which was given to the Chairman.)

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and precipitation records. The snow survey data used is the same as that which Honnold used. The precipitation records are those compiled a few years ago, including 1898 to 1934. We are making a re-examination of these, as Dean Clyde told you this morning. (Reads his paper, copy of which was given to the Chairman.)

Dean Clyde: Did I understand you to say that the precipitation during March is best?

Mr. Stanley: That was in Mr. Honnold's paper, I believe.

Dean Clyde: I've heard that before. I've also heard that the early snow creates the later summer water. I don't believe either one. It doesn't make any difference "when", just so long as it does come. Then too, I don't think that nine years is a long enough period to score with. There is one very interesting thing. The forecast on April first, this year, on the basis of the 1898 to 1934 figures, happened to yield the very same probable mean value as the April first snow survey. There was a slight difference in the mean. Does it then follow that nine years of snowfall are representative of forty years?

Mr. Stanley: The chart I have drawn shows March increase against the April-July with not as good a correlation. We have started our mathematical calculations on that, but the simple March increase against the runoff suggests something.

Mr. Bradley Cozzens: It is true that the March runoff can spoil our March first forecasts. But, do you have to measure just that increase - can't you take the total amount on the ground on April first?
Mr. Harold Conkling: That is exactly what we do. That is the criterion.

Chairman: It is certainly interesting when we reflect. Here is the problem: the water comes down on the earth and runs off. The runoff is, with question, related to precipitation in the form of snow, rain, hail, fog and other phenomena. I suspect that if we keep at this thing long enough, we will get in a corner. It was very interesting, Mr. Stanley, to be lead through your discussions. I am much concerned as to how we get the coordination in straight lines which apparently will lead to a useful clue. In some places the agreement appears to be excellent while in others some divergence is noted. Because of the nature of this problem it is beyond the fondest hope ever to expect a perfect solution. As long as weather plays a role we will never see the picture as a whole. Trying to solve such a problem is intensely interesting with many avenues of approach and possibly we are in this respect much like the old prospector - always expecting a hit "pay dirt". Your presentation of these valuable papers is most appreciated.

Dean Clyde: I would like to make this suggestion: we should all keep in mind this simple, basic relation - the runoff is the residual, and precipitation as the main source. Although we must use these methods of analysis, we must not lose sight of precipitation. We have not measured all of those variables yet. I think when we do measure them, we will find that the points line up very well.

Chairman: Yes, we often find we get more water with less snow. There is some reason for that. Maybe it's because we are not conscious of the effect of things of small order. I was talking with Mr. Rohwer. I said, "Charlie, can you imagine a great river like the Colorado having come to us as snow? Seventy-five per cent or more of that River's flow, at least three-fourths of Nature's handiwork is at times hard to imagine crystals or fine particles of moisture. It's difficult to imagine.
all that water — was in the form of snow crystals or fine particles of moisture." Isn't that hard to imagine? Therefore, why shouldn't we be intensely concerned in the relation between this phenomenon we call "snow" and the runoff. In our runoff studies we experience irregularities or what we are pleased to call discrepancies when actually we may later find this to be the true picture and not an accredited error.

In summing up this subject of forecasting the flow of the Colorado River, it might may eventually turn out that the end result will be the composite of the forecasts covering the headwaters and tributaries in Colorado, Wyoming, Utah and New Mexico. The forecaster intimately acquainted with the characteristics of the streams feeding the Colorado can estimate with more confidence and such estimates in the aggregate may result in dependable runoff forecasts of the river into Lake Mead.

If there is nothing further on the subject of methods of forecasting the filling of Lake Mead, we'll pass on to the next number on our program. Mr. Harold Conkling, Deputy State Engineer of California, will now tell us something about the relation of snow surveys and flood flows in California streams, Mr. Conkling.

Mr. Harold Conkling: I missed the boat by not being here this morning. We have never extended our snow surveys to the watershed of the Colorado in California. That is purely because of the financial consideration involved, although we might have been influenced by certain statements or intimations that there is no runoff from the Colorado River watershed in California. We are going to investigate that later on, in view of certain things that have been happening.
I was gratified in a way - I at least felt better - after hearing Mr. Stanley's paper and finding out that the forecasts on the Colorado River are not perfect. Ours aren't either.

We grade our forecasts, you understand, prior to yours for the Colorado River. We do all our work in a radius of four hundred miles north and south of Sacramento. That area consists of a great number of watersheds and the conditions principally are like the Colorado north and south of the river. The north is more dominated by the storms from the north and the south is more dominated by the storms from the south.

This year, in the extreme north, the snow pack is about seventy-five or eighty per cent of normal. In the extreme south, in the Kern River, it has just reached seventy-five or eighty per cent above normal. So, we make separate forecasts for twelve streams, ending with the Kern in the south and the general watersheds in the north.

When we grade the general results of surveys, the "good" are not off more than ten per cent; "fair" are off from twelve to twenty per cent; "bad" are off twenty-one to thirty per cent; "terrible" are off over thirty per cent. We don't know if that is the classification adopted by the rest of you or not, but it's ours.

I was struck by Mr. Stanley's statement that they got better results from the precipitation records than from the snowfall. Of course, we haven't had enough money to do scientific work covering this particular point. So, although I don't want to derogate any of the work of Mr. Paget, Assistant in the State Engineer's Office, who's in charge of the work, we simply haven't had the money to spend, with which we think we could get better results.

I was struck by the conditions differing in certain areas, that Mr. Stanley spoke of. Our poorest results are on the Sacramento, which was
forty per cent off. This gradually gets better, on the San Joaquin. In the Kings, we have had extremely good results. Nine out of ten forecasts have been within twenty per cent. Eight of the ten on the San Joaquin have been within ten per cent.

On the Feather, which has been the principal tributary to the Sacramento, only two out of six results are good. On the Yuba, we had only one out of eight that was good. So, we are all having the same difficulties and I won't harangue much on the differences of our methods. Each one of you fellows is more of an expert than I am, and I'm not going to get "expert" before experts.

We are very much interested in the phases of flood control. In this, we are more or less limited. From rainfall, in the Sacramento Valley and in the San Joaquin Valley, we get our violent floods. However, the great volume of the floods comes from northern California. Tulare Lake fills up from the flood waters poured in from the Kings, St. Johns and Tule rivers. They have reclaimed a great deal of Tulare Lake by diking and pumping the water out onto irrigated lands around it. This reclamation went on for a good many years - back in 1936, '37 and '38. The moment the lake fills and over-tops the dikes, many districts were wiped out. None of these suffered damage this year, and probably there is no danger in the immediate future.

Now, as to the use of these reservoirs on each of the streams in California. The reservoirs have a certain size, made primarily for irrigation, power development, etc. From snow survey data you can't predict much about the runoff from rain, but a lot can be learned from each one of those reservoirs, by the utilization of knowledge gained by snow surveys. We have tried to work out quite a volume covering
this point. I think we sent a copy around to everybody. It is entirely on paper, so far, but has permitted our working out a system that gives a limited amount of control.

Let's assume you feel that your forecasts could be about ten per cent off on a certain stream. You have to allow more space in the reservoirs in order to control the floods and you have to be very careful that your runoff estimate is close. In other words, you have to give ten per cent leeway, either more or less, and as the temperature increases in the Valley, you find by that time, the runoff has arrived. You can then determine, with considerable accuracy - in June or May - how much more water is going to come down, and then regulate your reservoirs accordingly. The dangerous high waters are mainly in the form of rain floods.

We think, also, that snow surveys are going to be very effective in the management of the Central Valley Project. I hope all of us here know how the Central Valley Project will be managed. There is a large canal being built from the San Joaquin River to Bakersfield - two hundred miles long. There is going to be an endeavor to put some of that water underground. The firm water is going to be put underground. That is, unless these gentlemen working on the project find out that this can't be done.

It is just conceivable that with some very wet years, you might find, without doubt, that you will have all the water needed. You should know by January first the possibility of filling the reservoir during the runoff season. Then, you could start using whatever water was left in the reservoir for spreading. By January first - certainly it might happen by February first or March first, then whatever could be gained by this more reliable information would enhance the underground water storage in certain areas.
I am confident that, as we continue with our studies, there will be more methods found for predicting flood flow so the excess water can be put underground in the months during the year from February to July, which would be quite an asset if the spreading is going to be as effective as it is thought.

Now, I have nothing more to say. I am very grateful for having been put on the program and if you have any questions, I'll be glad to answer them.

Chairman: Thank you, Mr. Conkling. Have you any questions concerning the discussion of California floods and groundwater storage?

We have never yet attempted a snow survey conference without having something from Dr. J.E. Church, Meteorologist, of the Nevada Experiment Station at Reno. What I was concerned with when I contacted the Doctor, concerning a contribution to this meeting, was to see if he had some timely suggestions on what to do in figuring out our forecast of runoff as based on April first snow surveys, when usually in Colorado we get a lot of snow later on in the month, as well as in May and June. That is probably one of those questions that has no definite answer. I don't know whether the point is covered in this paper. However, as I read this first paragraph, I see that that is exactly the subject which is kept by him. (Chairman reads Dr. Church's paper, copy of which is kept by him.)

As I read this, I am inclined to feel that I will have to re-read it and give it more study. I surmise from the Doctor's closing remarks, a maximum of thirty per cent correction in our forecasts of April first, that it all depends upon the question of whether it rains or doesn't rain. If it doesn't, we leave it as it is — but if it does rain, we put on thirty per cent. It is one of those illusive things.
Are there any questions? Last, but by no means least, we are going to have the pleasure of hearing from Mr. Julian Hinds, Chief Engineer for the Metropolitan Water District of Southern California, who will tell us of the importance of snow surveys on the Upper Colorado River drainage, as related to the water supply for the Metropolitan Water District of Southern California.

Mr. Julian Hinds: Mr. Chairman. I have been unable to figure out why I'm up here. If there's anything in the world I don't know anything about, it's the snow surveys. I'm interested, of course. However, as you move along in life, you'll see that they begin to put you on programs, just because you're toothless and bald-headed.

I would like to make a nice speech, but you have me discouraged. However, speaking from the point of view of the Metropolitan Water District, it is probable that if you keep working on this thing out, by the time it is essential for the Metropolitan Water District to know the answer, you'll have found how to do it.

As a matter of fact, it is not momentarily important from particularly a water point of view. There is quite a lot of water still coming down from the Upper Basin and that used in the Lower Basin is of a lesser amount. This we have, plus the water stored behind the Boulder Dam to level it out, at least for a few years at any rate. Before Boulder Dam was built, it would have been desirable to have known how much water to expect and how it was going to be distributed. You weren't making snow surveys then, but as time goes on the importance of such surveys will be thoroughly recognized. Of course, a prediction would be important if the reservoir filling was crowding the storage space, you would know whether to begin spilling or to run
extra water for power early in the year. In other words, if you conserve when you don't need to, some water could have gone out but didn't. Everyone in Southern California blames us, because we're responsible in the amortization. If you have dry years, it would be important to know early in the winter season, as far in advance of the summer season as possible, that we are going to be short of water, so that we could limit the water output and not do the other thing that might be detrimental.

Now, we come to those people in the West who are going to give the water to Mexico. It's going to be difficult for the people in California to know just how much water we are going to need. There will be long periods in the future when we are not going to have enough water, and it's going to be important that we cut the winter power requirements to the absolute minimum, and save for the summer. That is going to be hard to do in the winter, as we need that power.

The administration of water down here for power purposes is of primary importance in handling water down here for power purposes which is secondary to domestic and agricultural uses.

We have to know the picture as far in advance as possible, in order that we may have some strong arguments in defense of the plan of water management. By the time you get to this point of developing the science of forecasting you'll probably have nineteen years more than nine to chart from.

Chairman: We are grateful to you, Mr. Hinds, for your timely remarks and good council. This concludes our scheduled program and again I wish to express my sincere appreciation of the efforts all have made in taking part on this program to make this first meeting of the Colorado River Water Forecast Committee a success and it is with confidence that
I express the thought that because of the interest shown, and scope of the problems offered here for discussion, that this organization will continue with annual meetings of this sort over the years to come.

Now then, just before lunch, I mentioned that we were going to consider later this afternoon the real purpose of this meeting, that is, the problem of forecasting the runoff for the coming season. Since you are all well versed in this subject, in connection with the Colorado River, I am asking Arch Work to tell us what the details of this problem are and what we can offer in rounding out the picture as a whole.

Mr. R. A. Work: That sounds like rather a large assignment.

However, what we all want to know, in order to be able to tell the people in Portland, is the answer to the question they are going to ask me. This is the question they will ask, not only because they are interested in their own State, but in the whole Southwest: "What is the prospective water supply in 1945?" California will be getting a little water from other sources than the Colorado, and what I would like to be able to supply is as accurate an answer as can be furnished to me by all of the assembled groups represented here today.

Chairman: Would it be helpful to sketch on the blackboard the Basin of the Colorado? On the Green River, our reports indicate a normal supply. On the White, in Colorado, we say about one hundred and twenty per cent of normal on April first; eighty-five per cent for the Animas River, in Colorado, and about one hundred per cent for the San Juan, also in Colorado. That reviews the picture as we find it as of the first of this month. With those figures, in that order, I would venture the guess that the Colorado River flow in 1945 will be normal, or possibly a little better than normal.
We send out, each month, to our friends and acquaintances, who have information useful to us, a brief inquiry which is returned to us. We summarize these reports and draw conclusions, somewhat upon what these men have to tell us who are on the spot, so to speak.

In the upper Colorado River area, above Lee's ferry, we have a limited number of reservoirs. In general, I should say the aggregate to be about four hundred thousand acre-feet/capacity. There appears at this time no question as to the filling this year, also, there are many lakes and reservoirs of small size on the Grand Mesa. The water stored in the snow on this Mesa will average something like twenty-four inches and these small basins will likewise fill.

The Green Mountain Reservoir, 150,000 acre-foot capacity, a part of the Colorado-Big Thompson Project, and now practically completed by the Bureau of Reclamation, will fill to spill-way elevation. Because of the general outlook over the headwaters of the Colorado River in Colorado it can be concluded that normal runoff may be expected this coming season.

The general outlook in Wyoming is now very good, especially the North Platte. For the Green in the western part of the state the prospects are very favorable. When I left home last Saturday, at one place in Wyoming, they had a new snow cover of twenty-nine inches which will materially increase the 1945 runoff, especially the Big Horn in the northern part of the state.

Do you have anything else, Arch?

Mr. R. A. Work: If the group would like to have it, we can extend that a little bit westerly, and it will show there is some lack of uniformity in the various prospective forecasts. (Demonstrates on blackboard.)
Mr. Bradley Cozzens:  I guess Mr. Stanley has left.

I was wondering if anybody can furnish us with the information showing the accumulated precipitation data within a month after they occur. Some of the other States are quite lax in making their information available. It seems to me that there are some states where it's two or more months until that information is available in the released publication. Are there any more facilities from which this is available?

Chairman: We give out some advance information on snow cover to a few of our cooperators. We do this because of the apparent urgent need and in turn for the splendid support of our cooperative project. We release this information early for their own consumption, but not for publication. The record submitted has not been checked, it is just as we get it from the field, and is subject to correction later as found necessary. Sometimes a snow surveyor does not add the columns correctly. Our advanced information covers Colorado, Wyoming, New Mexico and a strip of area along the eastern part of Arizona.

Mr. Cozzens: Are you getting Arizona data early?

Chairman: Yes, we are making surveys on the Upper Salt and Upper Gila drainage areas in Arizona and western New Mexico. We use Weather Bureau records sent by wire from Phoenix. We also get direct information by wire from the Weather Bureau at Albuquerque. Personal calls are made to collect precipitation records at the Weather Bureau office at Denver and Cheyenne.

Mr. R. A. Work: That is a rough sketch of the prospective April - September, 1945, stream runoff, showing percentages on the average. The particular averages used in all States for all streams was the ten-year average of 1934 to 1943. That was a period when available water supplies closely approximated the water used and a period when we could
get adequate stream flow records, with a normal of about eighty per cent runoff, and a high of about one hundred and twenty per cent. There are isolated spots in Montana and Oregon where it ran approximately sixty per cent of normal. Around Tahoe there is also a little area below normal. In South-central Idaho, we have about a forty per cent deficiency.

You will all be interested in the general picture for the West, so if someone will attempt to trace the main stem of the Colorado, we'll have it.

Chairman: The outlook for the Colorado River, as far as our area is concerned in Western Wyoming and Western Colorado, from Wyoming to the San Juan, has been already mentioned. In New Mexico (there's not much drainage to this river in New Mexico), and in Arizona, and South, the contribution of the Little Colorado, Gila and Salt, as far as snow is concerned, is relatively small. So far our forecasts in Arizona have been relatively weak because of moderate temperatures and variation in snow cover. One of the principal difficulties encountered is the fact that we might have two feet of snow on the first of February and two weeks later the cover has been practically dissipated or the reverse may be found.

In theory, we need a record of accumulation - that is, building up each month, so that by April first, we will have enough data to enable us to tell what is going to happen. Sometimes all the snow courses are bare or zero water content. Then again, we may have three inches of water one year and one inch the next. We are somewhat at a loss as to what to take for/average, or normal, when the zero record plays so important a part in the forecast picture. It is obvious that no water
content would mean no runoff.

The contribution, in my opinion, of the runoff from snow in the Colorado from these Arizona streams is relatively small. So, the total flow of the Colorado is largely from the watersheds we have in the North, with Green River contribution at something like 100 per cent or normal. I would say that the runoff in the Colorado, consisting of the Yampa, White, and Colorado, proper, above Grand Junction, would be in round numbers between one hundred and five and one hundred and ten per cent of normal. The San Juan in southwestern Colorado, and its tributaries, (the Animas is a very substantial one), shows a normal condition. So, for the whole picture of the Colorado, confined to Wyoming, Colorado and part of New Mexico, we will have a normal flow or better. How much better, I don't know, but it's going to be better.

Two years ago, we made our May first surveys in the area of Steamboat Springs, Yampa River drainage, and so reported them. On the twentieth of the month there was twenty inches more of new snow. That can happen. If we get normal, or a little better than normal precipitation, which can happen, the result in runoff will be appreciable.

Mr. R. A. Work: Can't we amplify this picture a little bit and make it more complete? The storage situation in Colorado is better than average. The average storage for ten years in New Mexico is about forty-six per cent, with fifty-eight per cent there this year on April first. The average storage in Utah on April first is thirty-eight per cent, with the present figure being fifty-five per cent.
Nevada's April first average is forty per cent, and they have seventy-three per cent this year. Again, we see that 1945 storage is quite a little better than average. Wyoming has an average of thirty-one per cent and this year is running thirty-four per cent. There is not the difference in Wyoming average and capacity that exists in other States. This is in prospect from water in storage, and that to come.

Chairman: The next thing we want to discuss, gentlemen, has to do with the eminent success attained by the Columbia River Forecast Committee after nine years of experience. It was thought desirable to undertake some such committee for the Colorado River. With that in view, I was asked to make arrangements for providing a suitable program as an initial step in that direction. This was possible only with the aid of Mr. Blaney, who is the key man here in the City. He deserves more credit than I.

At any rate, the meeting was called, with a remarkable response to the call. We have, resulting from that call and generous response, accomplished much today. At least, we now have become acquainted and know something more about our objective.

It is in mind now, after such a splendid showing today, to call another meeting, similar to this one, possibly some time next spring. I might say that some of them present think that, in due time, such a meeting of this committee could be held somewhere in Colorado or Utah. I can assure you it is a real pleasure to come to Los Angeles and see the sunshine, however, some of the others present feel they would like to have a meeting of the committee somewhere up the river. This is a matter of future consideration.
I am wondering if, at this time, anybody has any comments to offer about the possibilities for future deliberations of a group such as this. I have sensed from the matter brought out here, and you will all note too, that the things we are discussing are almost identical with the Snow Survey Conference. It would be pretty hard to differentiate between the two.

The primary purpose of a Committee such as this is to forecast for the coming season. We didn't have that point in mind well enough at this time to accomplish much in this direction. As a matter of fact we should get all the information together having to do with the Colorado River and with these data, which can be sent to you post-haste when we get them, to be in time for your study so that when you come to the meeting you will be able to present your pet scheme on forecasting the season's runoff. At this meeting you will be able to present your comments on each other's methods, get new ideas, all bearing on the common problem of forecasting the runoff of the Colorado River. This feature of our meeting would be with the idea of making it of primary consideration supplemented with a program somewhat similar to that covering today's discussion. We could formulate, explain, and list the different methods used in arriving at the forecasts for the Colorado River, and assemble our conclusions in the proceedings of the meeting. It is likely we sometimes use a little intuition in arriving at our final forecast figures and this element of the problem would be difficult to pass on to others. Just now I wouldn't know how to do this thing, I think we should spend very profitably a certain portion of the day in explaining, rather than reporting. The solution of the forecasting problem is the all important thing and with all of us focusing our efforts in this direction something of value will come out of these meetings. These are suggestions for your consideration.
Mr. Harlowe M. Stafford: (U. S. Geological Survey, Los Angeles.)

- If the purpose of the meeting is principally to prepare the forecasts, it would seem that it should be called earlier in the year than the present meeting.

Chairman: We can get closer to the facts if we wait until April.

Mr. McLaughlin: The purpose of the meeting is not to prepare the forecasts, but to perfect our methods of forecasting. Mr. Chairman, realizing that you and Arch have to catch a train in a few minutes, could Arch tell us what he is going to do in Portland?

Mr. R. A. Work: The waters of the Columbia River are used for a great many purposes. An important use of water of the Columbia is for the growing of agricultural crops. The Columbia Basin, of course, covers a tremendously large area with the river and its tributaries heading in several of the Western States and British Columbia, and the water used for hydroelectric power, irrigation, navigation, and other purposes. In the early genesis of the snow survey work, there was a very strong demand from the Portland area for forecasts of the prospects of flow in the many streams of this basin. That was not our job at first, this being assigned to the United States Weather Bureau. They utilized all the help they could get from all quarters, to get facts for this purpose.

The Army needed such information when they were constructing Bonneville Dam, and the shipyards at Vancouver have for many years and at this time need Columbia River forecasts. Their ship building operations have to be suspended in years of high water in the river and at times the docks are flooded. To forewarn such possibilities was one purpose of the Committee, and it is gratifying to say that this Portland Forecast Committee served that purpose very well.

Another purpose was to bring together the people that were concerned with water problems along the Columbia River, that they might meet each other
and share information with each other. For instance, many make the same studies, where unification could be utilized. Strange as it may seem, there wasn’t any good method for disseminating all the information at hand. In the building of the Bonneville Dam, information was available from the Bureau of Reclamation. The various State agencies in Oregon, Idaho, Montana and Washington were concerned with the various phases of the program and were interested in the inter-related use of water within these States. In this, the Committee made a good clearing-house for the engineers to meet and share information.

The snow surveyors themselves have benefited tremendously by the existence of the Committee. It has provided an opportunity for Bill Lang to come to the meeting and tell those snow surveyors that they should do a better job in the future than they have in the past. Men, such as Lang, have given good constructive criticism. They have not just said, "You've got to do a better job." They have given us ideas and facts and met the challenge.

Then, there are those people interested in the overall picture. We will say a brokerage concern is interested in a certain sort of agricultural product, or let us say a railroad is interested in determining the prospective carloadings. They would have to get a report of snow conditions and runoff in streams for Idaho, Montana, Nevada and Oregon and elsewhere but there was no comprehensive, over-all picture of the stream basins as a whole. All of the reports are separate, and very few of you here in this room could get all of those reports. As I see it, it is the duty of this Colorado River Water Forecast Committee to see that a good picture is developed and presented to those who need it. Does that cover it?
Mr. McLaughlin: Yes, in a very brief way, of course.

Chairman: Mr. Blaney has just raised a question as to the membership of this Committee. We didn't attempt to exclude anyone, or to force anyone rather with the thought of encouraging all to come who to come if they didn't think they could benefit from the discussions.

The thing we are after is to meet here and discuss the general subject of forecasting.

The Committee will be a very large one, of course. Representatives being from different organizations who have to be concerned with water survey, and geological surveys, as well as power interests who use water for the generation of energy, and various other government and state organizations, such as the Weather Bureau, Army, Bureau of Agricultural Economics, etc. So, we sent out this call and I think extended a cordial invitation to come and join with us in this our first meeting. That would be my thought.

The ultimate purpose of such a Committee as this, is to sit around a table and discuss our results and attempt to strike the dominate chord that agrees with the coming runoff. That is what we are going to try to do.

Mr. McLaughlin: I think that is the policy that has been adopted - that the various interests are invited to participate. It is not a fixed committee, but a committee of agencies.

Chairman: That would be the prevailing thought. In this respect, I should like to say that we are doing a real service and we are happy in our work.

Again, may I extend to each and all of you my very sincere thanks for your attendance and the trouble and time spent in preparing your excellent papers. I trust that we will all have the pleasure of coming to Los Angeles again for another session of the Colorado River Water Forecast Committee.

If there is nothing further before us, I will declare the meeting adjourned.

4:40 P.M.
URGENCY OF FORECASTING IRRIGATION WATER SUPPLIES

R. E. Parshall

We are all well aware of the importance and general interests centered in the prediction of water supplies for irrigation, power, domestic and other purposes. Primarily the requirements of forecasts are to provide dependable statements as to the probable available supply of water during the coming runoff season as based on snow-water storage in the mountain country of the stream's watershed.

With us in Colorado and Wyoming, and all the intermountain irrigated areas, the planting program is pretty well fixed by April first of each year and because of this fact, water supply information is very desirable at a time even as early as January or February. In order to foresee the trend, or prospects for the coming season's runoff from various drainage areas of western streams, a study has been undertaken in the attempt to look behind the curtain of the immediate future and view the water supply outlook six months hence.

It is rather presumptuous to propose that there are certain relations existing between the runoff in some streams during the fall months and the coming summer flow. No attempt will here be made to explain why such relations seem to exist. The problem here discussed does not consider a factor of the precipitation occurring during the late winter or spring months in summing up the summer runoff. The orthodox forecaster of water supplies, using the element of precipitation as a basis, gives due consideration to the factor of retained soil moisture over the watershed as an element in the final conclusion of his predictions. To approximate the soil moisture throughout the drainage basin...
soil samples are taken at certain stations or places and the moisture content carefully determined and such data entered as a factor in the final analysis of the forecast. It is believed reasonable to assume that the fall flow of a stream is a much better index of the soil moisture over the drainage than is the spot soil sampling method to determine the degree of saturation.

The problem of correlating the fall and summer runoffs in certain streams in Colorado, Wyoming, and New Mexico has been under investigation for the past few years but with varying success. For some streams there appears to be quite a definite trend or correlation while for others the relations are discordant. As based on the results thus far obtained, it may be said that for some streams it is doubtful if any correlation will be possible, especially those where reservoir storage affects the fall runoff according to the dictates of priority of water rights along the stream, unless due consideration and correction be accredited for the flow diverted. It is not in mind at this time that the scheme of forecasting summer flow, based to the previous fall runoff, can be developed to the point of complete reliance on full confidence in the final conclusions.

To illustrate the method of approaching the problem the Animas River, in southwestern Colorado, has been selected as a typical mountain stream having minor flow interference due to reservoir storage upstream from the gaging station at Durango.

In the accompanying table the data is compiled thus: Column "A" gives the summer flow in thousands of acre-feet for the year indicated; i.e. for 1937 the April–July runoff was 418,000 acre-feet. The corresponding October,
November and December flows shown for each year are for the previous fall months. The total fall flow is shown as "B". Diagram 1 is the smoothing curve plotted to obtain the values in column "Cor. Oct." The total October, November and December precipitation in inches at Durango, is listed in the appropriate column of the table for the fall subsequent to the indicated year. The criterion factor, fall precipitation times corrected October flow, is shown, its purpose to be explained later. The column headed "Comp. A" is the forecast summer flows for the April-July period for the year indicated and $z$-values as determined by the P, Q and R curves shown in diagram 2. The interpretation of diagram 2 is based on the criterion diagram 3. The final column shows the percent of deviation between the actual April-July flow of the river and the computed or curve values from diagram 2.

It will be noted from the foregoing discussion that the elements necessary to forecast the summer flow are certain data available shortly after January 1st, namely, the October, November and December flow in acre-feet of the stream and for the particular problem here concerned, the total October, November and December precipitation at Durango. The river flow, as compiled by the published records of the State Engineer of Colorado, provides the fall runoff of the Animas River at Durango and from the records of the U.S. Weather Bureau was obtained the fall precipitation at Durango. To have these data readily available for current use would require special effort to compile the records for use early in January, particularly the river flow.

To illustrate the method of determining the forecast for the coming season let us consider the years 1933 and 1934. For the former year the fall flow, B, totals 40,000 acre-feet. The corrected or smoothed value of October,
diagram 1, is 17,000 acre-feet, actual 16.6. The precipitation at Durango, 
fall of 1932 was 3.12 inches. The corrected October flow, 17, times the 
precipitation 3.12, gives the criterion factor 53. In diagram 3 the point 
located by the total fall flow B, as ordinate, and the factor 53 as abscissa, 
shows this point to fall within the segment "Q", thus indicating that the 
forecast value from diagram 2 to be obtained from the "Q" curve which in this 
case is 340,000 acre-feet and the actual flow for the summer of 1933 was 
320,000, a deviation of 6 percent. As will be observed in diagram 2 that the 
plotted point for 1934 falls definitely in group "P". The criterion indicates 
forecast curve "Q" which for this year is in error and thus results in a wide 
deviation, as shown in the table. The year 1934 was a drought period, a 
record of minimum runoff, and because of such extreme variation fails to fall 
in line with the general trend of the flow of the stream. Over the headwaters 
of this stream the June 1938 precipitation at Cascade, some 25 miles or more 
upstream from Durango, was 5.32 inches, 4.14 inches above normal. Because 
of this extreme amount of rain the June runoff was much in excess of the 
normal for the month and probably a reason for the fact the deviation between 
the actual and forecasted summer flow is rather wide.

Of the remaining 16 years of the period of record an agreement of less 
than 25 percent is realized or approximately 90 percent of the total of 18 
years, 1927 to 1944 inclusive.

No claim is made for this method of forecasting as to its being infall-
ible. The main purpose or usefulness is to be found in providing a means 
whereby the probable water supply outlook for the coming season can be estimat-
ed within reasonable limits at a time much in advance of the coming irrigation 
season. This tool is also valuable in the guidance of making the official 
forecast as of April 1 based on the water content of the snow cover on the 
watershed.
It is with some reluctance that this method of forecasting stream flow is offered. First, it is somewhat ridiculous to assume that there is a relation between fall and summer runoff in a particular stream, and second, there appears to be no logical foundation for the criterion factor to be a function of the October runoff and the fall precipitation. The significance of these assumptions may later be brought to light. Therefore, at this time, nothing is offered in direct support of the premises underlying this method of forecasting and is to be taken for what it is worth. This, however, can be said, that had this method been developed in 1926 it would have been possible to forecast the summer flow of the Animas River, on a ratio of nine out of ten years, to within an accuracy of 25 percent or less for the succeeding period of 18 years.

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Flow in 1,000 acre-feet units.

* The 1945 forecast was made subsequent to the Los Angeles meeting.
SUMMARY OF STUDY OF THE FALL AND SUMMER
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ANIMAS RIVER AT DURANGO, COLORADO. SEPTEMBER 1945.

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Flow in 1,000 acre-feet units.

*The 1945 forecast was made subsequent to the Los Angeles meeting.*
Animas River at Durango

Diagram 1

Corrected Flow for October
Animas River at Durango
Diagram 3

Fall Flow "B"

Fall precipitation x Corrected October
RUNOFF AS RELATED TO FOREST COVER ON THE HEADWATERS OF THE COLORADO RIVER

By H. G. Wilm

Runoff from the headwaters streams of the Colorado River provides the largest part of the water yield of this basin. Of a total undepleted yield of roughly 18 million acre-feet per year at the Mexican border, over 16 million acre-feet or about 90 percent flows from the high-altitude watersheds of Colorado, Wyoming, and eastern Utah; and well over half of this yield comes from forested areas within and surrounding the National Forests of the basin. Because of their relatively high water yields, these forest-covered lands are extremely valuable. In general, their value for water production exceeds that of the other natural resources which they produce; timber, minerals, forage, and recreation. Based on average water values in Colorado, for example, watershed lands near the Continental Divide in this State have a capital value of at least 50 dollars per acre. Such high water-producing values mean that, as the natural resources of these high-altitude watersheds are developed, the use of other resources may often have to be subordinated to the needs of water production.

During recent decades men have devoted increasing efforts to the harnessing of the Colorado River, storing its water in reservoirs for irrigation and water power and spreading water over thousands of acres of irrigated land for the beneficial use of western people. In future years
these developments will be greatly intensified; already many new plans are being drawn for the construction of dams, the development of electric power, and the irrigation of large areas of land. As a result, great though the water resources of the river seem to be, it will become increasingly necessary to husband each year's supply; to know how much water is likely to be available on the average for human wants; to forecast annual yields in advance; and to obtain a maximum supply of usable water, especially from the highly productive areas on the headwaters of the river.

Of these tasks, the first three are of particular interest and importance to hydrologists, and a good deal of attention is being devoted to the very vital subjects of water yield measurements and the forecasting of yields from measurements of snow and rain. The fourth task, however, is of great interest to foresters as well as hydrologists, because foresters are responsible for the proper management of the high, forest-covered watershed lands that yield most of the basin's water.

Why is it that the forester should be so greatly interested in problems of water yield? Partly because such a large part of the total water supply of the Colorado basin comes from the forested upstream watersheds, and partly because the quantity and quality of water yields from these forested lands may be considerably affected by the forest cover and by the way it is handled. These influences may be either negative or positive, and they may vary a good deal in degree. On one hand, a forest tends to diminish the total supply of water to streams through consumptive uses; water is withheld from the soil by the forest canopy and, after the residue has reached and penetrated the soil, additional water is withdrawn by evaporation and transpiration. On the other hand, a forest develops favorable conditions for the penetration and storage
of water in the soil, and for the reduction or prevention of floods, soil erosion, and siltation. As a result of these influences, the total supply of water to streams may actually be increased by the removal of forest vegetation. But, where the soil is easily eroded and its capacity to absorb water is easily reduced, the net supply of usable water may be reduced because much of the total volume becomes unusable; it runs off the watershed in flash peaks containing quantities of soil washed off of the watershed surface.

When these influences are considered in terms of usable water yield it can be seen that the forester, through his management of forested watershed lands, must be called upon to play an important part in the basin-wide development of water supplied for the Colorado River. This fact is becoming generally recognized, but a number of major problems still lie ahead of us in working out profitable methods of watershed management. We have to learn just how and where forest vegetation may be removed for the purpose of increasing water yields, without damaging the capacity of the watershed to produce all important natural resources and without inducing floods or erosion. We must locate those areas that are easily damaged, and find out how they may be protected or improved in condition so that they will produce maximum supplies of silt-free water. And finally, we must learn just how great an influence on usable water supply and on general watershed productivity may be provided by planned manipulations of watershed vegetation.

We are only getting started on the solution of these problems. As yet we have only established the specific principles underlying the influence of vegetation on water yields and erosion; have begun outlining areas where the management of watershed vegetation may or may not be permitted; and have
obtained some quantitative data on the effects of timber cutting on water yields.

Since these last findings are rather striking, it may be worth while to summarize the experimental results which have been obtained up to this time in the headwaters of the Colorado River. In the Fraser Experimental Forest near the town of Fraser, Colorado, the Forest Service has established a series of experimental plots and two controlled watersheds for the purpose of finding out how the cutting of mature lodgepole pine timber affects water yields.

Up to now neither of the two watersheds has been subjected to experimental timber-cutting treatments, so that data are available only on the amount and distribution of water yields as affected by an uncut forest, and on the approximate magnitudes and sources of water losses. Even these figures are illuminating, however. Water yields, for example, from an area covered with virgin lodgepole pine and spruce have averaged about twelve inches, or somewhat under 50 percent of the annual precipitation. About 90 percent of this annual yield is from melting snow, and the rest is provided by rains falling during the snow-free season, from June through September. In accounting for the precipitation losses, we have estimated from hydrograph analyses that roughly two to five inches of water from melting snow are required each spring to satisfy soil-moisture deficits in the watershed and the draft of water from the stored snow, before stream discharge rates can begin to equal the volumes of water supplied by melting snow and spring precipitation. Probably six to eight inches more water are held back from the soil by interception and evaporation from the vegetation and soil.
As yet these watershed figures are only approximations, although they are supported by data from our experimental plots. In addition, the plot results have already shown the most probable immediate effects of timber removal on the yield of water to streams and on soil erosion in this area and forest type.

These plots, 20 in number, have provided records since 1938 on spring snow storage, melting rates of snow, net and gross rainfall, and soil moisture in the spring and autumn. For the first two years the plots were studied without treatment, so that the resulting data indicated the magnitudes of all the measured factors as influenced by an uncut forest of mature lodgepole pine. Then, in 1940, 16 of the plots were cut-over to leave reserve forest stands of several different densities, and four plots were left uncut. On four of the treated plots, all trees larger than 10 inches in diameter were removed, so that the remaining forest contained only an open stand of smaller trees; in sets of four, the other plots were cut-over to leave 2000, 4000, and 6000 board feet per acre of "merchantable" trees larger than 10 inches in size.

The results obtained up to now indicate losses of precipitation from an uncut forest that do not differ greatly from those estimated from the watershed studies; about 30 percent of the total annual precipitation has been removed by interception of snow and rain, and roughly 25 percent more by transpiration and evaporation from the soil.

Timber cutting has exerted pronounced effects on all of the measured factors except soil moisture, and these effects increased consistently with the relative intensity of timber removal. On the average, for example, spring snow storage was increased about 26 percent by the most intense timber cutting, and the effects of the more moderate treatments were proportionately smaller. Snow-melting rates were accelerated by the opening
of the forest to sun and wind, but the increased amounts of snow stored on
the treated plots tended to offset this trend, so that all of our plots
became bare of snow at approximately the same time each year.

The net amounts of precipitation reaching the snow and soil through
the forest canopy were also affected by timber cutting; on the average,
these amounts were increased about 33 percent by the most intense treatment.

Of all the factors studied, only one was not strongly influenced by
the cutting treatments; the autumn deficits in soil moisture below the
capacity of the soil to hold water. Apparently reductions in transpiration
induced by thinning the forest were largely offset by increased evaporation
rates, so that the total losses of water from the soil were relatively un-
affected by timber removal. Hence the autumn deficits depended mainly on the
amounts of net precipitation which reached the soil through forest canopies
of different densities; and, incidentally, on the total quantity and distrib-
ution of summer and early autumn rainfall. After dry summers, for example,
the autumn deficits were much alike under all of the treatments; and the
strongest treatment effects were observed after one wet season, when a good
deal more rain had reached the soil in the cut-over forest than in the
uncut areas.

When the data on all factors were combined, figures could be obtained
on the average amount of water that became available for streamflow as a
result of each of our cutting treatments. This amount was 10.34 inches of
water on the uncut plots, or about 42 percent of the average annual precipi-
tation. The most heavily cut-over plots, on the other hand, provided 13.52
inches—about 31 percent more than that supplied by the uncut forest.
As to any depleting effects of timber cutting on the soil, up to now, no noticeable erosion has been observed on any of the plots, aside from minor gullies formed on the steeper logging roads. Some conifer seedlings are beginning to appear on the cut-over plots; the carpet of forest litter and humus has hardly changed in appearance; and there has been relatively little invasion of any of the areas by herbaceous or shrubby vegetation.

How are these timber-cutting effects, as observed on our plots, likely to influence streamflow from a watershed covered with lodgepole pine? If snow storage and net rainfall are increased and soil-moisture losses are not greatly changed, the total yield of water should be substantially augmented. After a relatively wet summer season, the subsequent spring peak should start rising a little earlier, because soil-moisture deficits should be smaller and more quickly replenished; after a dry season the stream rise should not be altered in time. Ordinarily the spring peak discharge should be higher than before the cutting operation, and even summer discharges should be somewhat greater. In general, therefore, timber cutting should exert a beneficial influence on the volume and distribution of water yields.

Obviously these experimental results, obtained only in a single small area and forest type, cannot yet be applied universally to forest-covered watersheds on the headwaters of the Colorado River. They do, however, show what may be accomplished by an intensified program or soundly planned land management of these high-altitude lands. If improved watershed management practices can be applied to large areas of productive watershed, it may be possible to make a larger net supply of usable water available to the people of the Colorado River basin and of other great western rivers.
RELATION OF 1945 RUNOFF IN THE COLORADO RIVER TO POWER PLANNING

By W. A. Lang
Southern California Edison Co. Ltd.

Introduction

The purpose of this paper is to show the need for improving the accuracy of runoff forecast data for the Colorado River watershed, particularly as it affects the inflow into Lake Mead and the resulting storage available for power generation. Use of Boulder power output by the allottees is also affected by the runoff available to other hydro plants as well as the distribution of load to the various fuel-burning plants on a fuel oil economy basis. It will therefore be seen that a poor water year in both the Colorado River basin and on other West Coast watersheds would result in heavy demands for fuel oil to offset the deficiencies expected in hydro-generated power. Conversely, fuel oil requirements would be reduced as the water supply at either or both locations became more abundant.

1945 Forecast Data Available versus Requirements

Forecast data available as of April 11, 1945 indicate an April to July inflow ranging from a probable minimum of 6,700,000 acre-feet to a probable maximum of 12,850,000 acre-feet, with 9,050,000 acre-feet given as the probable mean. It can thus be seen that the above-mentioned forecast deviates from 26 per cent below to 42 per cent above the mean probable inflow. There is, however, no indication as to which one of the three probable values will more nearly approach the actual runoff. As an over-all approximation, the power generated by one acre-foot of water at Boulder Dam is equal to the power generated by one barrel of fuel oil at a steam-generating station. This variation
of 6,150,000 acre-feet between the minimum and maximum probable runoff during the April to July period represents a potential generation of 2,600,000,000 kwh. of electric energy which, if produced by steam, would require burning fuel equivalent to 6,000,000 barrels of oil. This makes it very difficult to program Boulder power resources with other sources of power generation available to the Pacific Southwest area. It is therefore highly desirable that forecasting of water resources available for Lake Mead should be developed to a degree of accuracy comparable with the forecasting of California water resources. California forecasts are usually accurate within 10 per cent of the expected runoff for the April to July period which produces about 80 per cent of the annual runoff.

Preliminary forecasts of Colorado River runoff should be made available as early as possible each Spring. This information will be used by the Boulder power allottees in programming their respective power resources for the ensuing operating year. Such data are particularly important during years of subnormal water yield. In order that power resources may be integrated in an economical manner, it is necessary that the capability of these resources be known to a fair degree of accuracy early each year.

California water resources are known to a high degree of accuracy by April 1st, and a fair estimate is usually available early in February. If similar data could be made available from the Colorado River watershed, the Boulder power allottees could plan their subsequent season operations to use Boulder power more efficiently.

Power Planning

During the war period, fuel oil is a very critical commodity. The War Production Board and the Petroleum Administration for War require fairly accurate long-range estimates of the quantity of fuel oil that will be required for power
generation far in advance of actual use. A fuel-oil schedule must be prepared showing the monthly requirements for 12 to 18 months in advance. This estimate assists the War Production Board and the Petroleum Administration for War in allocating and procuring sufficient oil to meet military requirements and still assure a sufficient supply of oil for power generation. At present, accurate estimates of water available for Lake Mead are not available until as late as June or July; consequently, it is nearly impossible, or at least very difficult, to efficiently integrate power resources and accurately determine fuel oil requirements in advance.

In order that critical fuel oil used for power generation may be kept at a minimum, the production or generation of power should be assigned to the most efficient fuel-burning plants. To accomplish this in a subnormal water year, the more efficient fuel-burning plants are operated at high load factors early in the year. Their output displaces hydro energy and the water saved is retained for release during those periods when low-efficiency plants would otherwise be required. For example, average efficiency steam plants which require about one barrel of oil to displace an acre-foot of Boulder water, by integration with Boulder power can displace low-efficiency steam plants which require two barrels of oil to displace one acre-foot of Boulder water.

Early information on an above-normal year is also highly desirable in order that plans may be made to utilize water for power generation which would otherwise be spilled to maintain reservoir flood-control levels. Occasionally such spill power can be used through the allottees' interchange facilities and thus save more critical fuel oil.

1945 Forecast - Edison System

Forecasts of water resources available to the Southern California Edison Company's hydro system in California indicate an April to July yield of
about 125 per cent of normal. The California resources used in conjunction with
the Boulder resources allotted for the period ending May 31st will be sufficient
to carry the system load without excessive use of fuel oil.

However, if an estimate of the Boulder resources comparable to the accu-

racy of our California forecast were available, definite plans could be made at
this time for the substitution of hydro-generated power for fuel-generated power
for the remainder of 1945. Such forecast accuracy would permit efficient plan-
ing and would result in fuel savings which are not possible when the Colorado
River resources are not definitely known until the runoff is nearly over.

Conclusions

Summarizing the above, it appears that all available means of impro-
v ing the forecasts of Colorado River runoff tributary to Lake Mead should be
investigated. This investigation should include a correlation between precipi-
tation and runoff as well as between snow surveys and runoff, since precipitation
records may provide an index of a subnormal or abnormal year well in advance of
snow surveys.

Early indications of runoff expectancy based on precipitation records,
although inaccurate, do provide some means of integrating Boulder resources with
California resources and Pacific Southwest area power demands. Efficient oper-
ation of integrated power systems requires that the first load increments should
be carried by stream-flow plants and the balance of the load divided between
storage-hydro and fuel-burning plants in a manner which will make for the best
overall economy. The amount of water available and the time of its availability
will largely determine the fuel-oil requirements and the possibility of substi-
tuting either spill power or natural gas to conserve fuel oil.

It is apparent, therefore, that an improvement in the forecasts of
Colorado River runoff will be of great aid in planning the use of power-generating
resources, and an improved forecast is necessary to insure the most efficient use of Colorado River water.

(Paper prepared for presentation at the first meeting of the Colorado River Water Forecast Committee at Los Angeles, April 16, 1945.)

W.A.L.
4-12-45
DISCUSSION ON THE PAPER TITLED "RELATION OF 1945 RUN OFF ON THE COLORADO RIVER TO POWER GENERATION" - PRESENTED BY MR. W. A. LANG

H.A. Lott

The paper presented by Mr. W. A. Lang and the remarks by Mr. Cozzens give a very excellent picture of the effect of run-off forecasts on power planning, however, there are a few points of emphasis which I would like to make. The entire southwest area is now producing electric power in the order of 22 billion kilowatt-hours per year, increasing from 14 billion kilowatt-hours per year since 1941. Boulder generation, which may vary from 4-1/2 to 6-1/2 billion kilowatt-hours per year, is, as you may see, a very substantial portion of the area's generation. When, as was pointed out by Mr. Lang, the difference between the minimum and maximum estimate of water available at Mead reservoir may vary as much as 6 million acre-feet, which variation is capable of generating 2.6 billion kilowatt-hours, which is likewise a substantial percent of the electrical load in the area, it becomes apparent that even when the differential is divided between several utilities, a good estimate of the water available at Boulder reservoir is quite essential to the utilities involved in planning their years operation.

If the percent error in forecasting Colorado River run-off could be reduced to 10 percent, the resulting inflow error of about one million acre-feet represents a potential electric generation in the order of 450 million kilowatt-hours capable of displacing steam generation requiring one million barrels of oil; the problem would be simplified since the difference is divided among several utilities.

From the planning viewpoint, poor water years in California cause the substitution of large quantities of steam generated energy for hydro energy. Under present war time load conditions, gas or oil fuel equivalent to 7 million barrels is required during an excellent water year, in average years 13 million barrels and in dry years fuel equivalent to as much as 19 million barrels is required for power production.

During the war period fuel oil is a critical commodity and a good estimate of the water resources at Boulder is necessary to program the use of fuel oil. It has been reported that when the war is over there may be a continuation of the need to conserve fuel oil and if such is the case equally accurate estimates of Boulder power availability, based on the forecast of inflow, will be required after the war in order that necessary fuel inventories may be built up and oil purchase contracts arranged when deficient inflow is expected.
While the figures which I have given you, in general apply to the entire area, the Edison Company is equally interested in better forecasts of inflow to the Boulder reservoir, in order that they may more effectively program the use of prospective Boulder power with other sources of generation.

H.A. Lott vs
Apr. 18, 1945
Mr. Lang has presented an effective story of the relation of the Colorado River run-off and Boulder power supply to the various allottees from that project.

The Department of Water and Power is in a position somewhat similar to the Southern California Edison Company, but its hydro electric power sources are considerably different. The only true hydro source which is largely dependent upon the natural resources of the water shed are those small plants in Owens Valley. The Aqueduct power supply is an assured capacity and with a relatively different energy output. This output varies, of course, with the water demands of Los Angeles, being greater in the summer months than in the winter, with greater energy output during the summer period. Due to the construction of the Aqueduct and storage facilities it is possible, however, during the reduced flow in the winter months to obtain higher peaking capacities than when the larger continuous flow is required during the summer months. This fits quite nicely the load requirements of the Los Angeles system, since its peaks are higher during the winter months.

The larger portion of our energy, however, comes from the Boulder Power Plant. This fact, coupled with the relatively continuous supply from the Aqueduct and minimum steam means that any deficiency in the Boulder supply will
require the generation of such energy from steam, oil-fired sources. As Mr. Lang has mentioned, one acre-foot of water at Boulder is equivalent to one barrel of oil in Los Angeles, so that the change of 1,000,000 acre-ft in the available water supply would mean 1,000,000 barrels of oil. Purchases of this magnitude could not be made on a moment’s notice, usually, and particularly under the present war conditions when oil is/rationed article, almost as difficult to obtain without priority and necessary requirements, as is meat.

It can be seen, therefore, that the earlier an accurate estimate is available, the better for all parties concerned in planning the distribution of their power production among the various sources.

With the Department, however, this condition is not quite as pronounced as with the Southern California Edison Company, since their information from the California watershed is available at a much earlier date than the Colorado River watershed, but will become more pronounced with the development of our hydro sources in Owens Valley.

We are particularly concerned about the variation in value present in the various forecasts; for instance, as mentioned in Mr. Lang’s paper, the run-off from April to May may vary from 6.7 to 12.8 million acre-feet, with a probable mean of 9.05. The run-off between August through March also has a very marked irregularity, as can be seen from the accompanying slide. In the vicinity of the 6.7 million acre foot prediction the variation may be between 2.8 and 5.5 million acre-feet.
Notes on Mr. Lang Paper

In the vicinity of 9,000,000, the variation is approximately the same magnitude, or from 3 million to 6.5 million; while in the vicinity of the maximum estimate it may vary from approximately 3 million to 7.5 million. You can see, therefore, that rather than the three values of the estimate, for the purpose of power generation, each one has a range in itself of approximately 3 million acre-feet, which must be estimated.

The next slide will serve to augment slightly, Mr. Lang's statements regarding the difference in time between the forecast for the Colorado River watershed and that for the California area. These figures are average, and, of course, do not represent the various deviations which may be present from time to time. As you will note, the large portion of the precipitation in California has occurred in the month of March, while in the Colorado River watershed, April and May and, in fact all months of the year, with the possible exception of November and June, contribute a large portion of the precipitation in the area.

The next slide shows these same data plotted as an accumulated curve and you will note that through March approximately 90% of the average precipitation has fallen in the California area, while in the Colorado River watershed approximately 75% has been made available, on the average.

This Department has made studies covering the
Notes on Mr. Lang Paper

Colorado River watershed for many years even prior to the construction of Boulder Dam. Studies of correlation between precipitation and the Colorado River run-off do show relatively high values even as early as December.

The next slide will serve to show this correlation. The lines are plotted as a continuous curve, although it should be stated that the first two points are for September and October without accumulation, while the months from January through April are all based on the complete accumulation of precipitation from September to the month in question, with the proper weight factor applied to each month's precipitation. This study is based on precipitation stations in Colorado only.

When the stations of the entire watershed are included the correlation coefficient including April of 91.5 is increased to 94.2. However, the deviation between prediction and actual is still present.

The following three slides show the prediction as compared with actual for the three periods ending February, March and April. As will be noted on the February slide the predicted run-off may be as much as 50% of the predicted value. The next slide shows the accumulation of data through March. These years which showed considerable variation came relatively close while with the data available through the month of April in all but the very unusual cases the predicted values are quite close to the actual run-off figures.
Notes on Mr. Lang Paper

Anything which can be done, particularly during this present and possible future emergency, when the fuel oil supply is so critical to our war efforts, to establish in advance the possible available water supply in the Colorado River watershed would be of particular value to every allottee from Boulder Power Plant.

BC/EW-6

April 16, 1945.
COLORADO RIVER AT BRIGHT ANGEL CREEK, ARIZONA
AUGUST-MARCH FLOW COMPARED WITH PRECEDING APRIL-JULY FLOW

SLIDE 1
ACUMULATED SEASONAL PRECIPITATION
AVERAGE MONTHLY VALUES

SLIDE 2
CORRELATION BETWEEN YEARELY RUNOFF OF COLORADO RIVER
AT BRIGHT ANGEL CREEK, ARIZONA
AND
PROGRESSIVE COMBINATIONS OF MONTHLY PRECIPITATION

SLIDE 3
PERCENT OF SEASON
PERCENT OF SEASON

SLIDE 4
CORRELATION COEFFICIENT IN PERCENT

SLIDE 3
PERCENT OF SEASON
PERCENT OF SEASON

SLIDE 4
CORRELATION COEFFICIENT IN PERCENT
YEARLY RUNOFF OF COLORADO RIVER AT BRIGHT ANGEL CREEK, ARIZONA

YEARNLY RUNOFF --- ACTUAL RUNOFF
--- ESTIMATED FROM SEPTEMBER-APRIL PRECIPITATION IN COLORADO RIVER BASIN

RUNOFF IN MILLIONS OF ACRE-FOOT

YEARLY RUNOFF OF COLORADO RIVER AT BRIGHT ANGEL CREEK, ARIZONA

ACTUAL RUNOFF
--- ESTIMATED FROM SEPTEMBER-FEBRUARY PRECIPITATION IN COLORADO RIVER BASIN

SLIDE 5

SLIDE 6

SLIDE 7
Revision of remarks of Bertram S. Barnes at meeting of Colorado River Forecast Committee, Los Angeles, April 16, 1945 (remarks followed discussion of Mr. Lang's paper, No. 6 on program).

Mr. Lang has pointed out the desirability of correlating observed precipitation directly with runoff, so that preliminary forecasts of seasonal runoff can be made without waiting for the results of the snow surveys. I believe that our Regional Office at Kansas City may have started on that job already, for Colorado River. The new Weather Bureau procedure for preparing long-range and seasonal runoff forecasts is almost entirely mathematical, it makes use of rather intricate correlations of temperature and precipitation data with runoff. As a result, we are able to state the chances, or odds, that the actual runoff will not depart more than a given percent from the predicted amount.

I have here a copy of a seasonal forecast for the Columbia River system, prepared in our Central Office and issued February 1, of this year. Predictions have been made of the seasonal runoff at 43 river points and for each of these points, 5 values are given. The first, in the left-hand column, is the figure that has 30 chances to one of being exceeded. In other words, it comes close to being a guaranteed minimum value. The next figure has three chances to one of being exceeded. It is a safe minimum to use when there is not too much at stake. The third figure is the "most probable" value in the strict mathematical sense. The other two figures have a one-in-three chance and a one-in-thirty chance, respectively, of being exceeded.

I believe that forecasts of this type will fill the need expressed by Mr. Lang. These forecasts are issued progressively. The first forecast may be made at the beginning of the season with the outside figures spread far apart. This spread of the outside figures takes care of the uncertainties of future weather. As later forecasts are made, the "one-to-thirty" and "one-to-thirty" figures are drawn in closer to the median while the "most probable" figure shifts gradually toward its final value or, as is sometimes the case, it simply fluctuates up and down.

The Sacramento office of the Weather Bureau has been making somewhat similar progressive forecasts for Sacramento River for the past two years, for the use of the Bureau of Reclamation. They are issued monthly, starting the first of January. The procedure used in making these forecasts was developed by an earlier process than the one used for the current forecasts for Columbia River. Three figures are given for each forecast, the middle figure being the "most probable" value. The lower figure is the value that would occur if the remainder of the season duplicated the driest previously on record and the upper figure would be realized if the remainder of the season followed the wettest on record. These Sacramento River forecasts have shown a close verification and their usefulness has been well established.
Suggestions for Improving Water Forecasts for Colorado River

Before undertaking the ambitious task suggested by the title assigned for this discussion it seems desirable to make a picture of the area from which Colorado River water in the main stream comes and to delimit within that area the part which not only produces the most of the water, but is also the principal area where snow surveys will be of value. There has not been time to implement the discussion with much statistical background, nor in fact, to analyze the whole area, therefore the observations offered will apply principally to Western Colorado and it is hoped will be taken as applying only qualitatively and roughly.

Of the area supplying the main stem of Colorado River, three states - Colorado, Utah and Wyoming contain 98,000 square miles and from these states comes most of the water supply of the river. Twenty three thousand square miles of New Mexico are within the river basin, but not over 10 percent of this area lying close to the head of San Juan river and along the Colorado boundary contributes runoff which reaches the main river. Small spring runoff and cloudbursts are the only contribution of the rest of the New Mexico area tributary to the main stream.

Generally accepted estimates compiled by different authorities are in substantial agreement that from these three states came not less than 90 percent of the total original flow of Colorado River. Present flow from these three states is probably a somewhat greater percentage of total outflow because consumptive use in the lower basin materially exceeds water production. It would be mistaken, however, to assume that all the 98,000 square miles in these three states is producing area. The actual fact is very different. The total area in Colorado is closely, 39,000 square miles. A hasty summary of areas above key gaging stations in Colorado at which an average annual runoff approximating 6 inches in depth appears, shows that this runoff came from a gross area above the gaging stations of about 23,000 square miles. This area is 60 percent of the total drainage area within Colorado.
A similar or perhaps a greater ratio of producing to total area may obtain in Wyoming but it is certain that the non-producing area in Utah is much larger than that from which usable runoff comes. It is probably very conservative to say that in these three states not less than one-half the area of 98,000 square miles contributes no useful runoff to the main Colorado River. As to this non-producing area it should be said that it contains great lengths of main and tributary river channels from which there is considerable loss. While from this typical "desert" area cloudbursts do contribute a little water and much silt and dissolved solids and there are in places small spring flows, the river has almost no perennial local tributaries and the actual result from this large part of the region is probably decidedly negative at all seasons and especially during high water.

Snow surveys cannot cover even one-half the total area nor is it necessary that they should. Local Weather Bureau records for considerable areas will immediately show what is borne out by knowledge of the country itself, that from some parts of the 23,000 square miles above key gaging stations in Western Colorado there cannot possibly be any useful runoff, although such areas are above the key gaging stations and there is no ready statistical basis for their measurement or exclusion. Certain criteria may however be applied in Colorado that should more closely delineate the actually producing area. In the other states these criteria might not exactly apply, as but will probably be close to the fact as they may be in Colorado, since even in that state these criteria are based on some assumptions.

It is a fair conclusion from extensive observation that in Western Colorado perennial supplies of water seldom originate below an altitude of 7500 feet. If on the map of Western Colorado showing the 7500 contour the lines designating the lower limit of an annual precipitation of 20 inches be superposed, the two will be found to coincide to a remarkable degree. At higher elevations will be contained within the 7500 contour the areas receiving greater precipitation, thus indicating roughly at
least, that total precipitation increases as some function of altitude.

Results of various studies of particular drainage areas in Western Colorado seem to indicate that typical mountain areas even when extending over considerable range of relief, consume water at rates of about 14 to 16 inches annually. This seems to check the fact that the area above the 20-inch limit of total precipitation corresponds rather closely with that which contributes an average runoff of 6 inches. It seems to afford a basis for excluding areas above the key stations actually known to be non-producing, since the limit of 20 inches annual precipitation is also quite closely the area within the 7500 contour. Lands in Western Colorado above this contour which are part of the main mountain mass extending westward unbroken from the Continental Divide contain 18,500 square miles. As to certain detached areas above 7500 feet lying west of the main mass, they are known to contribute little useful runoff, parts of them are outside the areas above key stations, and it is felt that no great error is set up by disregarding them.

Thus there is finally delimited an area of 18,500 square miles from which there is an average annual runoff of over 7,000,000 acre-feet of water (which is not, however the entire Colorado delivery), even during this period of reduced stream flow. This is the area within which useful information from snow surveys, as well as from other methods of obtaining water information, must come.

The geography of this 18,500 square miles is fully as important a factor, perhaps more so, than its rugged character topographically. The eastern limit is the boundary of the Colorado River basin at the Continental Divide. Probably at no place in Colorado is this divide lower than at Muddy Pass, between Middle and North Parks, where the altitude is 8770 feet. Its average altitude approaches 13,000 feet. From the Wyoming boundary south to Yampa River the producing belt is only 15 miles wide. From Yampa River south practically to the New Mexico boundary, a distance of 210 miles, the average width is 85 miles.

It would be an ideal situation if one snow survey course could be so located in
It would be an ideal situation if one snow survey course could be so located in the area of 18,500 square miles that readings of water content at that course were an infallible index of the runoff to be expected from all the streams of Western Colorado, or similarly an index, because of compensating local variations, for total delivery to Lake Mead. A snow survey course so located would automatically cancel out all variable factors, which, as experience accumulates, actually require allowances for their effects if forecasts of value are to result. It seems possible that in certain areas where snow surveying has attained results of phenomenal accuracy, conditions not too different from the ideal one proposed above have obtained. Even a casual study of the geography of Western Colorado seems to show that final results such as are needed will probably have here to be obtained the hard way.

For example, the 10 years record already compiled shows definitely that at Wolf Creek Pass near the head of San Juan river, on Grand Mesa, between the main Colorado and lower Gunnison rivers, and in the vicinity of Steamboat Springs on Yampa river, areas of considerable size accumulate much more snow and water content than similar areas anywhere else in Western Colorado. In large part the explanation seems to be that these three localities are headlands more or less advanced beyond the main mountain mass into the paths of the moist air from which precipitation comes.

Even this explanation, however, does not seem too certain nor applicable because the greater mass of the San Juan mountains, west of Wolf Creek Pass, does not appear to share in this large accumulation although it is higher and more exposed than the Wolf Creek country. On the contrary, Grand Mesa, which lies in the lee of the Uncompahgre Plateau and only a little higher, accumulates water to its western edge, while the Uncompahgre Plateau is only average snow country. Similarly the area east and north of Steamboat Springs, although in the lee of the Flat Top Plateau, seems to be much better watered than the latter. Records of runoff from these three areas, do not moreover, entirely bear out the expectation of greater unit flow.
Similar anomalies in records of stream flow, upon adjacent drainage areas, and in apparent accumulations of water in snow from drainage to drainage, as well as inconsistent results in runoff as compared to water in snow, lead to the inevitable conclusion that location of a few key courses that would have local significance as well as furnishing reliable information for lower river use will be a matter of extreme good fortune if it can be made to work. It is much more likely that as a result of prolonged observation and extensive trial an ultimate combination of snow survey courses and additional gaging stations may yield consistent results.

It will probably also be found that additional Weather Bureau facilities at high altitudes, or at least precipitation stations there working the year round, will be necessary if checks of fair accuracy are finally secured. Weather Bureau stations now active in Western Colorado number 57, of which 31 have records for 10 or more years and there are 23 inactive stations with similar lengths of record. Grand Junction is a station of the first order and Craig and Durango are second order stations, leaving 54 stations manned by voluntary observers, who for the most part turn in records of exceptional value so far as their facilities permit.

Naturally, volunteer observers are seldom located at the precise high altitude locations where weather records are really needed because even the few people who do live at those altitudes have naturally chosen the protected spots which are practically useless for obtaining records that represent precipitation in the high areas. For the general purposes of the Weather Bureau, moreover, stations will be located in towns or farming areas that have immediate use for the information obtained. It is to be hoped that experiments with unattended weather stations will justify a much more general use of them because it is believed that the final refinement of snow surveying may have need of much information that such unattended stations can furnish, particularly for that season of the year when there is no snow.
In the discussion that follows, as well as in the foregoing brief survey of Weather Bureau facilities, it is not the intention to be merely critical. The effort is rather to report facts along with logical and reasonable suggestions which the facts seem to justify. Too much of value has already been accomplished in snow surveying to warrant mere criticism. The effort should be to point the way for the better accomplishment that can surely be made.

When the snow survey courses on Colorado River drainage were laid out in 1936 the immediate need of basic information with which to operate lower river storage and power facilities was the paramount consideration. It was perhaps not then felt that too much of local value would be derived or desired from the original installation. Because of the necessity to proceed economically in setting up this large area of experiment one of the prime considerations was accessibility of snow courses to routes of automobile travel. This was so because there was no time to develop the accessories needed upon inaccessible courses and because of a hope, that was well justified, that such accessible courses would be sufficient. It is surprising how many of the present courses, especially at high altitudes, are of great value, but this is in large part due to the fact that many secondary routes as well as the main highways through the mountains are kept open all winter by the Colorado Highway Department.

There is room, however, for the establishment of a number of courses which will give a better picture of actual accumulation of water in snow. This will in many cases involve laying out new courses which after a period of coincident record will take the place of some of those now operating. One example in point can be cited. The station called Nast, at the head of Frying Pan River is at the last habitation up the river. It is in or near a valley of considerable size, in fact the largest valley on the river, at an elevation of 8700 feet. The record there, would seem to indicate that the accumulation of water on the head of Frying Pan river never reaches
a depth of 8 inches. A snow course located at Sellers, about one and one-half miles up a highway closed in winter would be more nearly at average elevation of the area and would give a much better indication of actual snow cover and water content on the Frying Pan drainage, which is probably at least twice that shown at Mast.

It would no doubt require an extra day to read the Sellers station, and this is the reason it was not originally established. The same sort of circumstances and the same necessity to consider the safety of observers led to many such locations. On the other hand a few courses have been set up since the original layout that amply confirm the fact that a good many stations not easily reached will in the end be needed to give a better picture of average conditions. Such changes will be justified whether the courses turn out to be natural indices of runoff or whether by use of the information from them a more accurate summary of supplies can be obtained and used in a strictly quantitative analysis of probable runoff.

Essential to the whole problem is the fact that in spite of its rugged mountain character where relief within very short distances is often measured in thousands of feet, Western Colorado is actually the sort of small featured country that results from a fairly well matured drainage system. Valleys are narrow or do not occur on many tributaries, streams are exposed to all points of the compass with widely varying precipitation due to such varied exposure, successive heights of land seem to blanket succeeding areas along the storm paths most effectively in some instances and almost to have the opposite effect in others. The record already acquired illustrates that variations in water content from basin to basin from year to year can be radical, apparently altogether inconsistent and not susceptible of easy explanation. The considerable width of the main mass of the producing area also makes for considerable inaccuracy if the record is obtained only from the heads of stream in that area, as is generally the case.
All these conditions seem to indicate that by a process of elimination and of substitution based upon considerable informal observation during winter seasons, there will finally evolve with some increase in the total number of snow courses, a system that will either extend into the numerous tributary areas that now seem to need such courses or will by coordination and correlation prove that a lesser number of courses adequately represents considerable areas where physical and geographic conditions are highly varied. As this system of snow courses develops it will naturally be more closely coordinated with the necessary stream gaging stations by means of which snow survey results must inevitably be checked.

It seems probable that adequate coverage of Western Colorado will require additional stations, perhaps a half more than are now operated, in order properly to document forecasting. Such an increase in stations carefully located will probably furnish the basis for more accurate results of local interest and may also insure that no large areas that might affect lower river results go unmeasured.

It seems to be high time to discuss here certain problems that are admittedly not the business of snow survey people, but which require attempts at solution if water forecasts on a numerical basis are to retain their validity either actually or as a basis of comparison. Mention was made of the long reaches on streams below the producing area from which there are known, or expected, large water losses. These same reaches will ultimately be the sites of a considerable number of large reservoirs having at least the dual purposes of power production and river regulation. When built the salvage effect of such reservoirs will be added to the salvage effect which will also follow further storage and irrigation, and even further trans-basin diversion from the headwater areas.

While the local circumstances are not at all similar the final effect of increased development on upper Colorado River will operate in the same general manner as has such development on South Platte and Arkansas Rivers, in Eastern Colorado.
over the last 80 years. When the development on these latter streams was started
neither flowed perennially out of the state, but the regulatory effect of irrigation
use in Colorado has made them both sources of constant flow across the state bound-
ary and at the same time has decreased spring flood peaks. If suitable records were
available it could be demonstrated that a considerable salvage of water has accom-
panied the more easily identified gains, and such savings of water can be quite
strongly inferred from records that do exist.

If well justified projects for use of Colorado River are to be undertaken, par-
ticularly in the lower river basin, upon sound premises as to probably water supply,
much more should be quickly learned about the actual present river regimen at all
points, in order that the effect of development as made may be properly assessed.
The application of this line of study to snow course surveying lies in the fact that
the quantity of such salvage will become another and changing factor for which proper
allowance will have to be made as development proceeds if accurate forecasts of del-
ivery to the lower river are to be deduced from water content in producing areas.

This study will be almost entirely implemented by establishing stream gaging
stations so located as to picture present conditions at or affecting the sites
where such large reservoirs will ultimately be built. Not the least of the values of
the study may consist in proof, in advance, that the large reservoirs projected are
or are not suitably tight basins where storage should be undertaken. Because of the
ultimate importance of such additional stream gaging to final forecasting accuracy,
as well as for its more ostensible purposes, it seems desirable that snow survey
people work in cooperation with others interested in this matter to set up the
necessary facilities.

Grand Junction, Colorado
April 10, 1945

F. C. Merriell
METHODS USED BY THE BUREAU OF RECLAMATION
IN PREDICTING FLOOD-SEASON DISCHARGE
OF THE COLORADO RIVER INTO LAKE MEAD

by

J. L. Honnold, Engineer,
Bureau of Reclamation.

Section 6 of the Boulder Canyon Project Act of December 21, 1928,
specifies that Boulder Dam and Lake Mead "shall be used; first, for river
regulation, improvement of navigation, and flood control; second, for irriga-
tion and domestic uses and satisfaction of present perfected rights in
pursuance of Article VIII of said Colorado River compact; and third, for
power." The past operation of Lake Mead has recognized these objectives
in the order indicated.

The most important source of income to the Boulder Canyon Project is
from power revenues. To obtain the maximum possible power production with-
out interfering with the other functions of Boulder Dam and Lake Mead
requires careful operation of the reservoir. Through prediction of flood
season inflow to Lake Mead, storage space which otherwise would be required
for flood control, may be safely utilized for power and conservation
purposes.

Reservoir releases in excess of 40,000 second-feet overflow the flood
plain and cause seepage water to appear in the cultivated valleys below
Boulder Dam. Through predictions of flood inflow to the reservoir, releases
in excess of 40,000 second-feet can be avoided except during extreme floods.
Forecasting of flood-season inflow to Lake Mead as far in advance of its
occurrence as possible, and with the greatest accuracy obtainable, is
essential in meeting these problems of reservoir operation.

The discharge of the Colorado River at Bright Angel near Grand Canyon,
Arizona, has been used by the Bureau of Reclamation as the inflow to Lake
Mead for forecasting purposes. The inflow to the river between Bright
Angel and Lake Mead is minor, and approximately offsets reservoir losses.

In general, the run-off of the Colorado River which reaches Bright
Angel is composed of:

(a) Primary low-water flows derived from ground water,
which is replenished by deep percolation from melting
snow, rainfall, and irrigation;

(b) Secondary low-water flows produced by local rains,
principally in the summer;

(c) Spring floods derived from melting snow;
Fall and winter floods produced by heavy rains in southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado.

Primary low-water flows derived from ground water present no problems in the operation of Lake Mead for flood control. Secondary low-water flows from local rains and fall and winter rain floods are unpredictable. Fortunately, they do not exceed 20 percent of all run-off at Bright Angel. Spring flows from melting snow, however, represent the major portion of all run-off, and the prediction of such flood volumes, therefore, becomes necessary in order to attain the desired ends of maximum power output and adequate flood control.

Predictions of run-off by this Bureau have been made by two methods, those based on snow-survey data and those based on cumulative precipitation at high-altitude stations. In 1936, when most of the snow-survey courses in the Colorado River Basin were established, the Bureau of Reclamation also established several high-altitude precipitation stations in the Basin in Colorado.

The Colorado River Basin above Bright Angel has been divided into sub-basins as indicated on the basin map. Weights have been assigned to each sub-basin based on the mean contribution of the sub-basin to the run-off of the Colorado River at Bright Angel during the flood season for the period during which snow-survey and precipitation data are available. The sub-basins and their respective weights are:

<table>
<thead>
<tr>
<th>Sub-basin</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green River in Wyoming</td>
<td>10 %</td>
</tr>
<tr>
<td>Green River in Utah</td>
<td>5 %</td>
</tr>
<tr>
<td>White and Yampa Rivers</td>
<td>16.5%</td>
</tr>
<tr>
<td>Colorado River in Colorado</td>
<td>25 %</td>
</tr>
<tr>
<td>Gunnison River</td>
<td>15 %</td>
</tr>
<tr>
<td>Dolores River</td>
<td>7 %</td>
</tr>
<tr>
<td>San Juan River</td>
<td>17 %</td>
</tr>
<tr>
<td>Unmeasured tributaries</td>
<td>4.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Surveys of depth and water content of snow have been conducted in the Colorado River Basin since 1936 cooperatively by the Soil Conservation Service, Forest Service, National Park Service, Office of Indian Affairs, Geological Survey, Bureau of Reclamation, Utah and Colorado Agricultural Experiment Stations, State Engineers of Utah, Colorado and Wyoming, and various irrigation associations, power companies, municipalities, and others. Four surveys are made each year, about February 1, March 1, April 1, and May 1. Records at 60 snow courses are currently used in forecasting the flood run-off of the Colorado River at Bright Angel. The average elevation of these 60 courses is 9370 feet, with 18 courses being at or above 10000 feet.
The average water content of the snow for all courses in each sub-basin is determined for each survey for each year since 1936. These average water contents of snow in each sub-basin have been weighted in accordance with the weights previously given, and the weighted mean water content of snow cover of the entire Colorado River Basin above Bright Angel determined. This weighted mean water content of snow has been correlated with the subsequent flood-season discharge of the Colorado River at Bright Angel for each of the forecast periods as shown on the chart entitled, "Forecasts of Lake Mead Inflow Based on Snow Survey Data." Due to the wide divergences of the limited number of points, envelope curves have been drawn on this chart to indicate the maximum probable, mean probable, and minimum probable run-off of the Colorado River at Bright Angel.

Fifty-five precipitation stations in the Colorado River Basin are used in the cumulative precipitation method of predicting flood-season inflow to Lake Mead. Twenty-one of these stations are above 8000 feet elevation, and the average elevation of all stations used is 7550 feet. Through studies of relationship of cumulative precipitation and run-off we have concluded that precipitation occurring prior to October has no appreciable influence on run-off after January in the Colorado River Basin. Precipitation accumulating subsequent to October 1, is used as a basis of four predictions of run-off to be expected at Bright Angel during the period between the date of the prediction and the subsequent July 31. These predictions, as in the case of the predictions based on snow surveys, are made on about February 1, March 1, April 1, and May 1 of each year. The mean cumulative precipitation from October 1 to the date of forecast is determined for each forecasting period, and weighted in the same manner as to sub-basins as is employed in the forecast based on snow-survey data. Correlations between cumulative winter precipitation and subsequent flood season run-off are prepared as indicated on the chart entitled, "Forecasts of Lake Mead Inflow Based on Cumulative Precipitation." Envelope curves showing maximum probable, mean probable, and minimum probable run-off of the Colorado River at Bright Angel are necessarily drawn for each forecast period, as in the case of the predicting curves based on snow surveys.

In comparing the snow survey and the cumulative precipitation methods used in predicting flood season inflow into Lake Mead, for the February 1 predictions, the average error in the mean probable prediction, based on cumulative precipitation, is 27 percent, while that based on snow-survey data is 31 percent. For the March 1 predictions, the cumulative precipitation method again appears to be a better correlation with an average error of 26 percent in predicting mean probable inflow, while that based on snow surveys is 31 percent. Both methods give an average error of 26 percent for the April 1 predictions of mean probable flood flow. However, on May 1, the snow-survey predictions have an average error of only 16 percent while the predictions based on cumulative precipitation have an
average error of 21 percent. With additional years of record on which to base the correlations and refinements in the methods used, it is believed that predictions of mean probable flood season inflow to Lake Mead can be made on May 1, with an average error of about 10 percent.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER BASIN

MAP

Legend
- Snow Survey Stations
- Irrigation Sections
- Sub-basin Boundaries

Sub-basin
- I
- II
- III
- IV
- V
- VI
- VII

* Figures in parentheses indicate number of reservoirs in each sub-basin.
FORECASTS OF LAKE MEAD INFLOW BASED ON CUMULATIVE PRECIPITATION

COLORADO RIVER AT BRIGHT ANGEL - MILLION A.F.

FEB.-JULY RUNOFF

WEEKS

APRIL - JULY RUNOFF

OCT.- MARCH

INCHES

WEIGHTED AVERAGE CUMULATIVE PRECIPITATION

OCT.- FEB.

MAY - JULY RUNOFF

OCT.-APRIL
FORECASTS OF LAKE MEAD INFLOW BASED ON SNOW SURVEY DATA

COLORADO RIVER AT BRIGHT ANGEL - MILLION A.F.

INCHES
WEIGHTED AVERAGE WATER CONTENT OF SNOW
COLORADO RIVER AT BRIGHT ANGEL - MILLION A.F.

APRIL - JULY RUNOFF

FEB. - JULY RUNOFF

MAY - JULY RUNOFF

MARCH - JULY RUNOFF

FORECASTS OF LAKE MEAD INFLOW BASED ON

CUMULATIVE PRECIPITATION

WEIGHTED AVERAGE CUMULATIVE PRECIPITATION

INCHES

OCT.- MARCH

OCT.- APRIL

OCT.-JAN.

OCT.- FEB.
Forecasting Colorado River Flows

(Preliminary outline of work done and work to be done on this subject in Office of River Control of Region III)

by J. W. Stanley and R. E. Kennedy

1. Introduction. - Forecasting of Colorado River flows is being made along two lines, first on the basis of measured water content of snow cover on the watershed, and second on the basis of cumulative precipitation on the watershed. The Denver Office has for several years been utilizing the snow measurements in making their forecasts. In earlier years, precipitation records covering the period 1898-1935 were assembled in the Denver Office for use in flow forecasting, but after a few forecasts were made, the method was abandoned. A re-examination of all these data is being made in an attempt to improve the precision of runoff forecasts. Wherever evidence of some unusual influence appears, it will be investigated in an effort to ascertain its effect. The following discussion is an outline of some of the work already done and some which will be done.

2. Factors causing extremes of runoff (both low and high) in years of normal snow cover. - It is obvious that there is a relationship between the water content of snow on the watershed, and the river flow in the spring and early summer. It is likewise evident that there should be a relationship between cumulative precipitation and total river flow. These are the basic propositions on which forecasting has been based, and if there were no other variable affecting the flow, it would be a simple matter to make the predictions.

There are other variables, however, which must be taken into account. This is illustrated by figure 1, which shows snow water content on March 1 plotted against runoff for the period March through July, for all the years of record, 1936-1944. Scatter of the points for these 9 years is so great that it is difficult to distinguish any relationship. In fact, the points show no statistical correlation when only the two variables, water and snow, are considered. For example, in 1936 the March 1 water content amounted to 18.2 inches (see table 1) and yielded a runoff of only 9.2 million acre-feet, while a 1938 water content of only 13.1 inches yielded 12.2 million acre-feet. The only alternative is to draw envelope lines (not shown on figure 1) by eye, enclosing all the points. Such lines would show only that the runoff in the 9 years ranged between 5 million and 13 million acre-feet.
Table 1.

Water content of snow on Colorado River Watershed and measured runoff at Bright Angel

<table>
<thead>
<tr>
<th>Year</th>
<th>DENVER OFFICE</th>
<th>Runoff of Colorado River at Bright Angel m.a.f.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1936</td>
<td>10.2, 18.2, 19.10, 10.20</td>
<td>9.5</td>
</tr>
<tr>
<td>37</td>
<td>6.5, 11.9, 16.02, 10.80</td>
<td>10.2</td>
</tr>
<tr>
<td>38</td>
<td>9.1, 13.1, 17.86, 12.54</td>
<td>12.5</td>
</tr>
<tr>
<td>39</td>
<td>9.2, 13.0, 13.31, 7.86</td>
<td>6.9</td>
</tr>
<tr>
<td>1940</td>
<td>6.6, 10.7, 11.13, 7.56</td>
<td>5.4</td>
</tr>
<tr>
<td>41</td>
<td>7.9, 10.9, 15.02, 16.14</td>
<td>13.4</td>
</tr>
<tr>
<td>42</td>
<td>7.2, 11.1, 14.8, 12.3</td>
<td>12.6</td>
</tr>
<tr>
<td>43</td>
<td>10.0, 12.7, 15.8, 5.8</td>
<td>8.6</td>
</tr>
<tr>
<td>44</td>
<td>6.4, 9.4, 13.9, 14.5</td>
<td>11.3</td>
</tr>
<tr>
<td>45</td>
<td>6.7, 10.71</td>
<td></td>
</tr>
</tbody>
</table>

* Figures marked thus supplied by Office of River Control.

In using the 1898-1935 precipitation records as prepared by the Denver Office, a significant correlation is obtained between March 1 cumulative precipitation and runoff (see figure 2), although the degree of accuracy of forecasts is not great. That is, in 9 years out of 10, the March through July flow can be predicted within ± 4 million acre-feet of the actual. That still is a range of 8 million acre-feet.

Studies made thus far have not revealed what may be done to improve the March 1 forecasts. As regards the April 1 forecasts, however, an important clue has been utilized which appears to be applicable to both cumulative precipitation and snow data, namely, the effect of percentage increase during the month of March.

It has long been recognized among Rocky Mountain "snow men" that March snows make the summer runoff. This means that the large snowfall must come during the month of March or later, and not in February or before.
Percentage increases occurring in water content of snow during March are indicated for each year on Figure 1. Also shown are percentage lines, which are intended to illustrate how the forecast on April 1 might be improved. For example, in the year 1936, there was an unusually high water content on March 1, but by April 1 there had been an increase of only 5% over that of March 1. The years 1939 and 1940 showed small increases also. It is inferred that years having negligible snowfall during March usually will be years of low runoff, and that the runoff will increase with increasing March snowfall.

Positions of the percentage lines on Figure 1 were determined by eye. Statistical analysis of the data has been begun, however, and has been carried far enough to indicate that the principle is applicable, provided the 9 years of record are approximately representative of a long period of years.

A further illustration of the effect of March snow increase is given by Figure 3, which shows simply the relationship between gain in inches during March, and the April-July runoff. Statistical analysis of the data of Figure 2, assuming again that the 9 years are representative, gives a highly significant correlation, and indicates that in 9 years out of 10 the April-July runoff could be predicted within ± 2.2 million acre-feet. This is a range of 4.4 million acre-feet as compared with a range of about 5.5 million when using the April 1 snow data enclosed by envelope lines, and about 6.6 million when using April 1 precipitation data.

The fact that the increase in snow during March appears to be an excellent index of subsequent runoff suggests the possibility that the precipitation occurring in March may also be a good index. Results of preliminary study indicate that a fair correlation does exist. If the precipitation occurring during both March and April is used, a better correlation results.

The conclusion to be drawn from the foregoing discussion is the adage mentioned earlier, namely, that "March snow makes the summer runoff," modified by the statement that April conditions exert a further, although usually a less important, influence. It is believed that our April 1 forecasts can be considerably improved by analyzing the data by the methods described.

3. Weighting of sub-basin snow cover and precipitation. - In the past the snow cover of each sub-basin has been weighted according to the average contribution to total runoff during the period 1936-1942. The 1896-1935 precipitation data were weighted in a similar manner, using average contribution over a long period of years.

Even though the desired precision of forecasts on April 1 and May 1 apparently may be obtained by use of methods described in the preceding section, which include weighting according to average runoff contribution, other methods of weighting sub-basins are being tested in the hope of improving forecasts on the earlier dates.
The effect of weighting the sub-basin snow cover according to area rather than to runoff contribution has been investigated, with the result that the scatter of points is much the same. A similar scatter developed when no weights were used. The simple average water content of all snow courses has been plotted against total runoff, with a resulting correlation which appears to be about the same as that obtained by weighting according to areas.

A brief study has been made of five snow courses close to stream gaging stations in an attempt to determine the existence or non-existence of relationships between snow cover and runoff in individual sub-basins. Shown on figure 4 are graphs of water content, plotted against runoff as measured at the respective gaging stations, for the March 1 snow surveys.

The time devoted to the study of weighting sub-basins has been short and has been applied to snow course data only. It has been included in this discussion merely for the purpose of illustrating another of the problems to be attacked during the course of our investigation.

4. Long-range forecasting. - This moot subject is not introduced with the promise that long-range forecasting can be accomplished. However, because of the great benefit which would be realized if it were possible even to predict whether the coming year's flow would be low or high, it is believed to be a subject worthy of investigation. It is not planned to inaugurate such an investigation until the short-term forecasting procedures have been carried to satisfactory completion.

Mr. Rolla H. Wahle, in his paper "Stream Flow Forecasting by Pattern-Behavior," published in 1943 National Research Council Transactions, Part III, suggests the possibility of applying the principle of pattern-repetition to the problem of forecasting river flows a year in advance. Application of this principle has been surprisingly successful in forecasting Columbia River flow for the last six months of the water year on the basis of the first six-months' flow. The question of whether it would be successful in forecasting a full year in advance remains to be answered.

5. Summary. - For the immediate future, it is planned to extend the precipitation records through 1945, study methods of weighting sub-basin precipitation and snow cover, complete the work of improving the April 1 and May 1 correlations, and attempt to improve the February 1 and March 1 correlations. These items of work probably will not be completed before the end of 1945 and possibly not until sometime in 1946. It is hoped that investigation of long-range forecasting may be started in 1946.
Figure 1

LAKE MEAD FORECAST
MARCH-JULY (INCL) DISCHARGE
COLORADO RIVER AT BRIGHT ANGEL

Weighted Average Water Content of Snow Cover on Watershed
MARCH 1

Percentages refer to ratio of March increase to March 1 water content.
Figures refer to years.
Figure 2

March-July Run-off into Lake Mead

October-February inclusive weighted precipitation 1898-1935
% Normal

March 1, Forecast
Correlation of
Run-off vs Precipitation
Lake Mead
Figure 3

Relation of April-July run-off to March increase in water content of snow on snow course.
Figure 4

INCHES OF WATER IN SNOW MARCH 1

Fraser River near Winnebago Park, Colo. Watershed 28.5 sq. miles

No unmeasured diversion

All stations:

60
50
40
30
20
10
0

INCHES OF WATER

ALL SNOW COURSES

MARCH 1
WATER ON SNOW COURSE

AND

MARCH-JULY RUN-OFF

FOR COURSES CLOSE TO GAGING STATIONS.

COLORADO RIVER BASIN
Snow surveys in California are confined chiefly to the Sierra Nevada Range lying east of the Sacramento and San Joaquin Valleys. A few snow courses are maintained in the Coast Range and also in the Tehachapis but these are more or less experimental. The snow courses in the Sierra are entirely utilitarian in character and are used to forecast the summer runoff to the Sacramento and San Joaquin Valleys where, because of the highly developed use of water, efficient programming of the available water supply is essential.

Although the Sierra Nevada lies many miles from the watershed of the Colorado River it has a kinship with the Colorado River Drainage in that the northern portion is effected by the storms from the north and the southern portion is to a greater extent effected by storms from the south. For this reason adjacent watersheds lying north or south of each other, may and do vary considerably in their relative snow pack and measurements must be made in each watershed for an independent determination of the river flow to be expected when the snow melts.

Over California's 17,000 square miles of snow pack there are 236 snow courses, most of which have a back record sufficient for forecasting. The balance are new courses which are not yet aged sufficiently.

Various degrees of success in runoff forecasting have been reported from the 11 western states. In California the snow survey work has been successful in forecasting within a practical degree of accuracy. Grading the forecasting results according to the standards suggested by the Western Snow Conference where forecasts within 10% of actual are classed as "Good", those from 10% to 20% as "Fair", those between 20% and 30% "Bad", and those over 30% as "Terrible", the following summary indicates the degree of success of California's forecasts published during the past 10 years:

```
ANALYSIS OF FORECASTING RESULTS

<table>
<thead>
<tr>
<th></th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Terrible</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Sacramento</td>
<td>4</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Feather</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Yuba</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>American</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Mokelumne</td>
<td>6</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Stanislaus</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Tuolumne</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Merced</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>San Joaquin</td>
<td>8</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Kings</td>
<td>9</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Kaweah</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Kern</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56</strong></td>
<td><strong>39</strong></td>
<td><strong>13</strong></td>
<td><strong>1</strong></td>
<td><strong>109</strong></td>
</tr>
</tbody>
</table>
```
In this summary of the results achieved, it is found that since 1933 when the regular forecasting began, about 50% of the results have been within 10% of accurate, another 35% have been between 10% and 20% of accurate and the other 15% have been off over 20%.

This summary also brings out the fact that the forecasting success is weakest on the Sacramento Drainage System where the snowmelt runoff is only 40% of the annual total.

On the San Joaquin Watershed where the snowmelt runoff is 70% of the annual total, the forecasts are much closer.

It has been stated that "the melting snow cover over the mountain country contributes at least 75% of the water of the Colorado."

On the basis of California's experience with streams having such runoff characteristics, snow survey forecasting on the Colorado should work very well.

Consideration has been given in California to the use of the snow survey information as a tool in the control of floods, due to melting snow.

A method for doing this has been worked out by the snow survey department of the State Engineer's office and a pamphlet has been published describing in detail a logical method of operating a reservoir under conditions not unusual today where one reservoir is often utilized for the multi purposes of flood control, power generation, and water conservation for irrigation.

The method of reservoir operation suggested as a result of our study is a sort of "fence straddling" operation. On the basis of the snow survey information, the reservoir during the early part of the snow melt season is held low enough to absorb indicated snow melt flood peaks and yet high enough to insure that it will fill.
This sort of fence straddling was kept up until well along in the snow melt season when the temperature-streamflow relationship would indicate whether the forecast was going to turn out to be too high or too low and the reservoir during the last part of the snow-melt season could be operated accordingly.

In the case of Exchequer on the Merced it was found that power output was reduced when flood control was practiced. In such a case the resulting problem would not be so much one of engineering as one of economics. Would enough be saved by flood control to offset the reduction in power revenues?

The snow survey information could also be used advantageously in water spreading work to recharge depleted underground storage as this could be started just as early in the winter as the snow survey indicated there would be a surplus of water during the following summer.

The more accurate the snow melt runoff forecasts can be made, the easier it is to operate a reservoir.

It seems reasonable to expect that as time goes on and as more study is put into the matter that the accuracy of forecasting from snow surveys will improve.

Such forecasts should be valuable in the operation of Lake Mead.

State Division of Water Resources
Sacramento, California – May 15, 1945

Harold Conkling
Fred Paget
Forest Rangers do much of the snow survey work in California.
California's snowpack covers 17,000 square miles.
150 men travelling in pairs or trios cover 4500 miles on skis to measure California's snow pack.
The Problem of Forecasting Runoff Based on April 1 Snow Surveys when a large portion of the snow cover at high elevations occurs during the month of May

Dr. J. E. Church

This week two forecast conferences are being held in Los Angeles and Portland for the two major streams that drain the western side of the Continental Divide.

The problems being considered are widely diverse for the Columbia traverses a storm belt with increasing precipitation toward its mouth while the Colorado enters a rainless belt and receives with the exception of the intermittent Gila little accretion downstream.

The streams are far from being adapted to their potential service. The Columbia exceeds the Colorado in volume (151,710,000 A.F. at the Dalles as compared with 17,489,000 A.F. at Yuma, computed 1922). The Columbia therefore has far more water than available land while the Colorado far is overburdened with land to serve. Consequently, forecasting of the Colorado water supply has become an earnest and delicate task.

Fortunately, as compensation for its desert area, its great watershed of 225,000 square miles is reduced for forecast purposes by almost one-half and the crest line of 760 miles is diminished to 330 miles.

Furthermore, three tributaries, the Green (5,797,760 A.F.), the Upper Colorado (6,650,200 A.F.), and the San Juan (2,745,270 A.F.) furnish 87.1 percent of the mean annual runoff at Yuma. Moreover, their April-July runoff attains 67.0 to 75.0 percent of the annual, thus establishing their snow-fed character.
The maximum divergence, where complete records are available as in 1914-17, between the seasonal percentage of the major tributaries and the main stream at Yuma is 14.5 percent and in the case of the April-July runoff is only 6.6 percent. Even where the comparison depends upon a single tributary and the main stream, the maximum divergence has not exceeded 25 percent and during April-July has usually been less than 10 percent.

These records are the result of an earlier study before Lake Mead was and include the effect of the Gila. The close agreement during April-July is due almost entirely to the quiescent stage of the Gila, whose normal runoff during this period amounts to only 1.4 percent of the total normal April-July runoff at Yuma.

The task of forecasting the runoff of the Colorado is therefore one of concentration on the three main feeders mentioned. To understand these better, at the suggestion of F. C. Merrill an atlas of the percentage of all of the contributors of the Colorado is being prepared, and such of the work on the Upper Colorado has been completed.

In latitude, elevation and temperature the Continental Divide does not differ essentially from the Sierra Nevada and the phases of major flow closely correspond with each other.

A comparison of the San Joaquin and Upper Colorado will be sufficient for illustration. The former has watershed elevations of 10,000 to 13,000 feet altitude and a normal April-July runoff of 1,439,800 A.F.
<table>
<thead>
<tr>
<th></th>
<th>San Joaquin Runoff</th>
<th>Upper Colorado Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feb. 5.00</td>
<td>Apr.-July 1,459,800 A.F.</td>
</tr>
<tr>
<td></td>
<td>Jan. 5.96</td>
<td>Apr.-July 1,880,000 A.F.</td>
</tr>
<tr>
<td></td>
<td>Dec. 2.30</td>
<td>Jan. 2.02</td>
</tr>
<tr>
<td></td>
<td>Nov. 1.35</td>
<td>Jan. 2.04</td>
</tr>
<tr>
<td></td>
<td>Oct. 1.48</td>
<td>Jan. 2.06</td>
</tr>
<tr>
<td></td>
<td>Mar. 8.07</td>
<td>Feb. 3.37</td>
</tr>
<tr>
<td></td>
<td>Apr. 13.48</td>
<td>Mar. 8.12</td>
</tr>
<tr>
<td></td>
<td>May 20.37</td>
<td>Apr.-July 21.22</td>
</tr>
<tr>
<td></td>
<td>June 24.62</td>
<td>June 32.07</td>
</tr>
<tr>
<td></td>
<td>July 11.63</td>
<td>July 13.63</td>
</tr>
<tr>
<td></td>
<td>Aug. 3.69</td>
<td>Aug. 5.77</td>
</tr>
<tr>
<td></td>
<td>Sept. 2.06</td>
<td>Sept. 3.02</td>
</tr>
<tr>
<td></td>
<td>Apr.-July 70.10</td>
<td>Apr.-July 75.04</td>
</tr>
<tr>
<td></td>
<td>Dec.-Mar. 21.33</td>
<td>Dec.-Mar. 9.49</td>
</tr>
</tbody>
</table>

Of the two streams there is a tendency for the major runoff of the San Joaquin to begin in March whereas the Upper Colorado begins only in April and runs over slightly into August. This makes it possible to use the May 1 survey as a basis for forecasting with a loss of only 2.35 percent of annual as compared with April 1.
Unlike the precipitation in the Sierra Nevada, the precipitation on the Continental Divide is evenly distributed throughout the seasons of the year. The corresponding decrease in precipitation during the winter and increase during April-July, when the run-off is in progress, increases the difficulty of determining the correction factors for excess or deficiency of precipitation during this period. However, the difficulty is not extreme as in the Saskatchewan basin east of the Continental Divide.

The detailed data on precipitation are again given in tabular form. The seasonal phases of precipitation in the Sierra Nevada, as represented by Fordyce Dam, are prefixed for purposes of comparison:

<table>
<thead>
<tr>
<th>Phases of Mean Annual Precipitation over Colorado Watershed with Addition of Phases at Fordyce Lake in Sierra Nevada for Purposes of Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage of Annual</strong></td>
</tr>
<tr>
<td><strong>Fordyce Dam</strong></td>
</tr>
<tr>
<td>California</td>
</tr>
<tr>
<td>6,500 ft.</td>
</tr>
<tr>
<td>1894-1916</td>
</tr>
<tr>
<td>70.97 in.</td>
</tr>
<tr>
<td>Dec.-Mar.</td>
</tr>
<tr>
<td>Apr.-July</td>
</tr>
<tr>
<td>July-Sept.</td>
</tr>
</tbody>
</table>

However, the efficiency of rainfall as compared with snowfall depends upon the presence of a snow cover upon which rain can fall and therefore escape the priming loss when it falls on soil. For example in the Susquehanna Basin of the Appalachians, altho snow constitutes
one-third of the annual precipitation, it is far more effective than
the remaining two-thirds. Thus the 28.83 percent of precipitation
at Grand Junction will be far more effective than the other 61.78
percent but will naturally be aided by the 31.0 percent during April-
July so far as the latter falls on snow.

It is this aid or lack of aid (if the precipitation fails) that
may distort the forecast. This distortion stalks in increasing
intensity from the Pacific as the April-July precipitation becomes
relatively heavier, but the maximum effect of 100 percent deficiency
on the western slope of the Continental Divide is only 30 percent of
runoff, for there are no lakes such as Tahoe to be directly affected.

The following table affords an overall picture for the West.

### Winter and summer precipitation in Western States and Provinces

<table>
<thead>
<tr>
<th>Region</th>
<th>Precipitation (Inches)</th>
<th>Ratio of summer to winter precipitation (percent)</th>
<th>Estimated percent of runoff for 100 percent deficiency in summer precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sierra Nevada: Colfax, 1870-1923..</td>
<td>37.52 6.39</td>
<td>(18.2)</td>
<td>(16.2)</td>
</tr>
<tr>
<td>Humboldt Basin: 6 stations, 1918-30..</td>
<td>6.31 3.83</td>
<td>(60.7)</td>
<td>(22.7)</td>
</tr>
<tr>
<td>Logan Basin: 5 stations..</td>
<td>7.06 6.72</td>
<td>(95.2)</td>
<td>(35.6)</td>
</tr>
<tr>
<td>Continental Divide: Durango, Telluride, and Leadville, Colo...</td>
<td>7.78 6.67</td>
<td>(85.7)</td>
<td>(30^a)</td>
</tr>
<tr>
<td>East of Continental Divide: Denver, Colo..........</td>
<td>3.22 7.67</td>
<td>(238.2)</td>
<td>(75-90)</td>
</tr>
<tr>
<td>Calgary, Alberta.........</td>
<td>2.99 8.52</td>
<td>(234.9)</td>
<td>(75-90)</td>
</tr>
</tbody>
</table>

\(^a\)Approximate
The maximum of 30 percent is only a remote possibility. A revision of forecast can be made May 1 based on the abundance of precipitation in April and its proportion of the April-June normal.

The plan of a double forecast for April 1 and May 1 can be tried as is being done for March 1 and April 1 on the Humboldt River, Nevada. This will permit the study of the gain or loss in snow cover upon which runoff most directly depends.

Nevada Agricultural Experiment Station

April 14, 1945

J. E. Church
The issuing of this report, covering the first meeting of the Colorado River Water Forecast Committee, Los Angeles, April 16, 1945, has been greatly delayed due to various causes and necessity of attention to other more important assignments. It is hoped that the material herein contained will be valuable and a contribution to the general subject of forecasting water supplies for irrigation, hydroelectric power, municipal and other important uses.

This report issued at the Colorado State A & M College, February 15, 1946.

Edited and prepared by R. L. Parshall, Senior Irrigation Engineer, Irrigation Division, Soil Conservation Service, Fort Collins, Colorado.

R. L. Parshall
Senior Irrigation Engineer
Mr. R. L. Parshall  
Colorado Agricultural Experiment Station  
Fort Collins, Colorado  

Dear Mr. Parshall:  

I am returning to you the transcript of the First Annual Meeting of the Colorado River Water Forecast Committee, held at Los Angeles April 16, 1945. 

You will note that Mr. Ewing and Mr. Scobey have suggested some editorial changes in certain parts of the record, but we feel that papers submitted by other than Division personnel should not be changed here. 

I wonder if your Station can do the cutting of the stencils for the mimeographing of the report, and we will run them off in this office. I suggest this procedure because we are badly handicapped here by lack of clerical help. In this way release of the report can be expedited, because if we were to do the complete job at Berkeley, it would have to be done as opportunity permits. 

Very truly yours, 

W. W. McLaughlin, Chief  
Division of Irrigation
Dear Ralph Parshall:

Thanks for sending me the letter from Mr. Lawson. I am returning for your files.

Read over your report on the Colorado River Snow Conference with plenty of interest. Several mistakes crept into the record. These I noted in the text sent out to Mr. McL. Believe I also has a few suggestions. I will list these items for you to use as you wish.

Page 8, near bottom: PURSUE—not Pursue.
Page 10, middle: Weather prediction? or do you mean precipitation?
11. middle: make FORECASTS instead of surveys?
12. middle: Situations instead of Statements
16. near bottom: "occurs in agreement," should you add, say "with normal"
17. several places: speaks of BILLIONS of gals. of oil. Should be "Millions"

This is verified later in text.
21. top of page: See Barnos revising of remarks on page some 30 or 40 further along. Believe the wording should be something like this;

"---the odds are three to one it will be exceeded.---On the fourth, the chances are three to three it will be exceeded. The firth is the odds are four to five that it will be exceeded."

27. Harold Conkling: Query. What snow falls in California in Colorado River drainage basin. Salton Sea is not Colorado River basin except by large stretch of imagination. By exactly same token Great Salt Lake is in Snake River Basin. Lake Bonneville discharged for ages into Snake Basin.
28. top: "south of Sacramento" not THE Sacramento
29. middle: Tulare Lake never got a quart of water from NORTHERN California.
30. near bottom: Add the word River to San Joaquin. Atm bottom something missing.
32. near bottom: follow "basin; that" with "being used"
39. change imminent to eminent.

I think most of these are errors on the part of a steno not familiar with the subject. Also a man talking on his feet will say things he never would write.

I see Paul Ewing has a number of other editorial changes and suggestions on the copy of the text sent out here, just in case you contemplate mimeo sets.

Regards
Those present were:

Allison, John M.  
Andrews, H. J.  
Bates, John S.  
Bocarde, G. B.  
Breithaupt, L. R.  
Burtner, John  
Canfield, G. H.  
Christensen, C. P.  
Codd, Ashton R.  
Criddle, Wayne D.  
Darlington, S. P.  
Drager, Frederick E.  
Captain, C. E.  
Edington, W. Dale  
Ellis, Jesse D.  
Fisher, Elmer  
Frame, S. R.  
Frost, W. T.  

Meteorologist, U. S. Army Engineers, 628 Pittock Block, Portland, Oregon  
Regional Forester, U. S. Forest Service, Post Office Building, Portland, Oregon  
Assistant Chief Operator, 64/4 Walnut, Coulee Dam, Washington  
Pacific Power & Light Company, 920 S. W. Sixth Avenue, Portland, Oregon  
Extension Economist, Oregon State College, Corvallis, Oregon  
Extension News Editor, Oregon State College, Corvallis, Oregon  
District Engineer, U. S. Geological Survey, 606 Post Office Building, Portland, Oregon  
U. S. Bureau of Reclamation, Coulee Dam, Washington  
Associate Hydrologist Engineer, U. S. Weather Bureau, 711 Federal Office Building, Seattle 4, Washington  
Associate Hydraulic Engineer, Division of Irrigation, Soil Conservation Service, Box 835, Boise, Idaho  
Office of War Utilities, War Production Board, Room 2714 Temporary R Building, Washington 25, D. C.  
Hydrology Section, U. S. Army Engineers, 628 Pittock Block, Portland, Oregon  
Associate Engineer, Bonneville Power Administration, P. O. Box 491, Vancouver, Washington  
Operating Engineer, Northwestern Electric Company, 920 S. W. Sixth Street, Portland, Oregon  
U. S. Weather Bureau, Portland, Oregon  
Hydraulic Engineer, Water Rights Branch, Parliament Building, Victoria, B. C.  
Assistant Hydraulic Engineer, Division of Irrigation, Soil Conservation Service, Box 1149, Medford, Oregon
<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harper, Frank B.</td>
<td>Division of Information, Soil Conservation Service, Portland 7, Oregon</td>
</tr>
<tr>
<td>Hartman, George F.</td>
<td>In Charge of Hydrology Section, U. S. Engineer Office, Seattle, Washington</td>
</tr>
<tr>
<td>Hon, Ted M.</td>
<td>Secretary-Manager, Scappoose Drainage District, Scappoose, Oregon</td>
</tr>
<tr>
<td>Hudson, William W.</td>
<td>Equipment Engineer, Kaiser Co., Inc., Administration Building, Oregon</td>
</tr>
<tr>
<td>Jackman, E. R.</td>
<td>Oregon State College, Corvallis, Oregon</td>
</tr>
<tr>
<td>James, John S.</td>
<td>Field Representative, Irrigation &amp; Drainage, Office of Production, Portland</td>
</tr>
<tr>
<td>Johnson, Frederick J.</td>
<td>Chief Clerk, Engineering Department, Portland General Electric Co., Portland, Oregon</td>
</tr>
<tr>
<td>King, Arthur</td>
<td>Extension Service, Oregon State College, Corvallis, Oregon</td>
</tr>
<tr>
<td>Kohler, Karl O., Jr.</td>
<td>Regional Engineer, Soil Conservation Service, Portland 7, Oregon</td>
</tr>
<tr>
<td>LeFever, C. L.</td>
<td>General Superintendent, Northwestern Electric Company, Portland 4, Oregon</td>
</tr>
<tr>
<td>Leupold, Norbert</td>
<td>Engineer, Leupold &amp; Stevens, Instruments, Portland 13, Oregon</td>
</tr>
<tr>
<td>Linsley, Ray K., Jr.</td>
<td>Associate Hydrologic Engineer, Weather Bureau Office, Sacramento 9, California</td>
</tr>
<tr>
<td>MacArthur, Charles A.</td>
<td>Hydraulic Engineer, Bonneville Power Administration, Portland, Oregon</td>
</tr>
<tr>
<td>Marr, James C.</td>
<td>Irrigation Engineer, Division of Irrigation, Soil Conservation Service, Boise, Idaho</td>
</tr>
<tr>
<td>McBirney, Harold R.</td>
<td>In Charge Portland Airport Station, Weather Bureau Airport Station, Route 4, Box 801, Portland 11, Oregon</td>
</tr>
<tr>
<td>McCauley, Thomas, Jr.</td>
<td>Assistant Plant Engineer, Columbia Aircraft Industries, Portland 14, Oregon</td>
</tr>
<tr>
<td>Merritt, M. L.</td>
<td>Ex-U. S. Forest Service (Retired), Portland 12, Oregon</td>
</tr>
<tr>
<td>Nielsen, Niels I.</td>
<td>Agricultural Statistician, U. S. Bureau of Agricultural Economics, Portland 5, Oregon</td>
</tr>
<tr>
<td>Peterson, E. N.</td>
<td>Coordinator, Northwest Power Pool, Portland 2, Oregon</td>
</tr>
<tr>
<td>Phelps, Howard T.</td>
<td>U. S. Forest Service, Division of Operation, Portland 13, Oregon</td>
</tr>
<tr>
<td>Phillips, Kenneth N.</td>
<td>Associate Engineer, U. S. Geological Survey, Portland 5, Oregon</td>
</tr>
<tr>
<td>Sporseen, Stanley E.</td>
<td>Engineer, U. S. Army Engineers, Portland 5, Oregon</td>
</tr>
<tr>
<td>Stevens, Henry R.</td>
<td>Bonneville Power Administration, Portland 14, Oregon</td>
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<td>Swedlund, Herman A.</td>
<td>Agricultural Statistician, B.A.E., Division of Statistics, Portland, Oregon</td>
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Mr. Work called the meeting to order at 9:18 o'clock a.m., and proceedings were had, as follows:

**PROCEEDINGS**

This is the seventh annual meeting of our water forecast group for the Columbia River Basin. Today's program will be longer than usual. Representatives of several agencies associated in the snow survey work have consented to lead various phases of the discussion in this meeting.

The principal phases to be discussed are: first, a review of snow surveys and related data, including reservoir storage, soil moisture, ground water, and so forth, for the Columbia Basin, under the leadership of Mr. Narr, Irrigation Engineer of the Soil Conservation Service, from Boise. Mr. Narr is in charge of federal-state snow surveys in the Columbia Basin. The second phase will be discussion, under the leadership of Mr. Canfield, District Engineer of the Geological Survey in Portland, of probable distribution of the flow of the main Columbia this year. A third phase, under the direction of Mr. E. Y. Peterson, Pacific Northwest Power Coordinator, will deal with probable effect of the impending water shortage upon power planning. The fourth phase, under guidance of Professor Breithaupt, Extension Economist of Oregon State College, will include discussion of the implications of water shortage upon agricultural planning and production this year.

Some of you may have special problems, so we should have your statement of those problems. There may be men here qualified to give you data that will help in answering your problem. Please feel free, each of you, to fully enter into the discussion.
In order to have a registration of the attendance, we will pass these cards. Please either print or write your name so Miss Mulvey can decipher it more readily than she can decipher mine.

We will try to finish this morning, but I don't believe we can, so we had better plan to return after lunch. I am sure we will be through by three o'clock, if not sooner.

Mr. Codd has an announcement as to luncheon today. Mr. Codd wants to have a showing of hands on how many will be there.

Mr. Codd also has another announcement regarding a supplemental conference that the Weather Bureau wants to have with certain of its cooperators.

Would you like to make these announcements now, Mr. Codd?

Codd: Luncheon is set for 12:15 at the Georgian Room in the Old Heathman Hotel, which is about a block and a half from here. Luncheon has been arranged for fifty. How many will attend the luncheon? (Hands raised) Twenty-seven, -- twenty-eight. Well, we will plan on thirty.

As to the other announcement of our cooperators' meeting, things have changed since I wrote to you, Arch, and we are going to skip that little detail.

Work: All right. I would like to ask, gentlemen, that you please submit your written material to Miss Mulvey before you leave the room.

Now, the snow survey work in the Pacific Northwest is accomplished through close cooperation of a great many agencies, - private, state, federal, and otherwise. One of the agencies contributing a great deal to the snow survey program, in the way of personnel, energy and facilities, is the United States Forest Service. We are privileged to have with us this morning the leader of the United States Forest Service in this Pacific Northwest Region, Mr. H. J. Andrews, the Regional Forester. Mr. Andrews is no stranger to the West Coast. For some years before he went East, Mr. Andrews was in charge of the Division of State and Private Forestry here in this area, and also was connected with the Northwest Forest and Range Experiment Station; consequently, Mr. Andrews is thoroughly familiar with problems of the Pacific Northwest. Mr. Andrews, it is a real pleasure to our group to have you with us this morning. We shall welcome such comments as you have to offer concerning the role of forests and watersheds in the production of this vital substance, water.

Andrews: Mr. Chairman and members of the Columbia Basin Water Forecast Committee: The U. S. Forest Service has been interested for a very long time in the management of forest and range lands and in the related subject of water. We still have a lot to learn. For the most part, as I understand it, the rain falls on the just and the unjust alike. I don't know whether the snow does the same, but because most of it does fall on the national forests, I hope we are not to be blamed for shortages of snow this year.
This snow survey program is one of the best examples of a truly cooperative endeavor that I have ever seen. Mr. Marr told me this morning that it takes the efforts of some two thousand men to keep track of the amount of snow; of course, they are employed only a short part of the year on that particular job, therefore, many agencies need to cooperate in furnishing people for short periods of the year for this work. If numerous agencies didn't cooperate, I don't know how the forecasting could be done, because no one agency could or should employ two thousand men just for that duty alone. Our Service is glad to have a part in this program.

It seems hardly necessary that I make a statement as to the role that water plays in the economy of the West, although I sometimes wonder if we completely realize the value of the water we have, or altogether appreciate the role that it plays in our western economy. I am always impressed by the viewpoint and comments of people who have come West in the last several years, beginning with people from the Middle West who came out here in the Dust Bowl period. We should be conscious of their rather vehement statements that they are never going back to a place where there is any question of adequate water.

As time goes on, timber cutting is reaching farther and farther back. The day may not be too far in the future when we will feel the pressure for timber. Cutting then might have an effect on the deposition and melting of snow. The Forest Service has done some work in that field. There is much work yet to be done. I hope that we shall always be able to continue management of forests in the high country so that the best influence of the forests on snow accumulation, snow melt, and run-off is not hindered.

Now, you snow surveyors are slowly gathering a tremendous volume of data. Not only are you increasing the data you have, but every year I expect you are getting better at it; and the better you get, the more we will all profit. There is little we can do to regulate rainfall or snowfall, but your data will help to better understanding of these phenomena, and to best use of resulting water.

As I first prepared my talk, it was to welcome you all to Portland and to offer you the facilities of the Forest Service Conference Room. Since the place of meeting has been changed, I still can welcome you to Portland and I do wish you every success in this meeting; you are prophets, and I can only hope that as prophets you are honored in your own country. Thank you. (Applause)

Work:

Thank you, Mr. Andrews. Almost as effective as prayer in bringing rain is the water forecaster's role in forecasting a dry season. It works nearly every time. (Laughter) We are greatly indebted to Mr. Derry, Manager of the New Industries Department of the Pacific Power and Light Company for use of their Conference Room here.
Now, Mr. Marr, we will turn the meeting over to you for a review of the Pacific Northwest snow survey data.

We are favored again this year, as we hope we will be for many years to come, with the presence of our friends from Canada. We will call on Mr. Webb, first, to give his story about conditions in Canada. Mr. Webb represents the Dominion Water & Power Bureau. Have you something for us, Mr. Webb?

It is always a pleasure to meet here with our friends who are studying the water resources the same on this side of the border as we are in Canada. The Columbia, rising, as it does, in British Columbia, seems to give us the first opportunity at the water, and our Mr. Frame, I think, is going to have first opportunity at the prediction of what water is going to pass down the Columbia.

I didn't realize the water shortage was so great until I got up to shave this morning in the Pullman. I found that they were fresh out of water, so I had to use a little of the ice water to shave with. This leads me to think that conditions are getting pretty critical down here.

Our preliminary forecast, as of March 1, has been distributed, I think, fairly well, and our records will contain reference to it. Mr. Frame's report contains in some detail the information in regard to snow and run-off predictions in our country. There is one comment that I should like to add, and that is in regard to the run-off of the Columbia River at Birchbank. The run-off for the 6-months' period from October to March during the past year was 81 percent of the long-term mean. That is information of some value.

It is a pleasure to be here, and I will listen with interest to what goes on. Thank you very much.

We thank you, Mr. Webb. Your information that run-off at Birchbank for the 6 months beginning October 1 was 81 percent normal is of considerable value. More should be added about the early run-off in the various streams over the country as indicating what the conditions of the ground water table might be.

Now, we should like to have Mr. Frame's snow report for the Columbia River in Canada. Mr. Frame is Hydraulic Engineer with the Water Rights Branch of the Department of Lands at Victoria, B. C.

Mr. Chairman, it is a great pleasure for me to be with you all again. I should just like to say that Mr. Davis was very sorry that, for personal reasons, he was unable to attend this year.

Now, I will read my report so I won't be saying things I might be sorry for afterwards. This is the report that is presented by Mr. Davis each year at this time. It has a map attached showing the Columbia Basin in Canada. Part of my report, you will note, deals with the coastal area.
The majority of the snow courses indicated that the snow cover was slightly less than average with a consequent lower water content, while those in the East Kootenay area indicated less than one half the usual amount.

At some courses in the Interior areas the ground was found to be frozen but for the most part the soil was quite moist without giving indications that any run-off had commenced. Winter temperatures were slightly above the average.

Excepting the East Kootenay area, it is expected that the water run-off will not be much less than that of a normal year. Others may differ with me on that a little. There should be no flooding conditions unless abnormal precipitation and temperatures prevail.

COASTAL AREA:

In the Powell River area the snow cover was lighter than usual, the water content in the snow being 10 percent below average. However snow at higher elevations approaches more nearly to normal, the greatest depth being 9 feet at elevation 3100. The April to July (inclusive) run-off from Powell Lake is estimated to be 90 percent of a 26-year normal, or 787,000 acre feet.

In the Vancouver area snow had all disappeared from the courses having low elevations. There was 6 feet in snow depth on Grouse Mountain, the water content of which was 30 inches, being 96 percent of an 8-year average.

The new course at Tashme was deplete of snow, although where shaded, there were approximately 2 inches on the ground.

At all courses where snow was found, indications were that run-off was about to commence. No frost in the ground at any of the courses.

Reservoirs are still somewhat below normal, however since the soil beneath the snow cover is quite wet, most of the run-off should find its way without much loss, directly to the streams, with consequent beneficial effect on the reservoirs.

OKANAGAN BASIN:

The water content of the snow in this area is 104 percent of a 9-year average. The soil moisture index figure of 1.03 indicates that the amount of moisture in the ground at the beginning of snowfall was nearly twice that of last year, the figure for which was 0.57.

The forecast for the inflow to Okanagan Lake is for 286,000 acre feet being 97 percent of the normal April to July (inclusive) inflow for 22 years.

NORTH THOMPSON AREA:

The North Thompson River at Barriere will have near to normal run-off as indicated from the water content of the snow cover. It is
expected to discharge about 6,000,000 acre feet between April 1st and the end of July.

KOOTENAY - COLUMBIA BASIN:

The water content in the snow cover in this area is 59 percent of last year, 102 percent of 1942 and 79 percent of average. Apparently there has been no loss of water content excepting that from evaporation. The depth of the snow pack at the higher elevations approaches that of normal years.

EAST KOOTENAYS:

The Elk River at Elko is expected to flow about 46 percent of its average giving about 544,000 acre feet from April to August inclusive. The Kootenay River at Wardner is predicted to have a run-off of 51 percent of average or 1,949,000 acre feet. Smaller streams in this area will probably have a correspondingly light run-off.

The courses in this area showed less than half the usual amount of snow with a consequent low water content. One course was deplete of snow.

Normal April rainfall, covering periods up to 28 years as ascertained from four representative precipitation stations, is 1.27 inches. The normal April to August inclusive precipitation is 8.93 inches.

NORTH KOOTENAY AREA:

Inflow at the north end of Kootenay Lake is estimated at 75 percent of normal, or a flow 1,588,000 acre feet from the Lardeau and Duncan Rivers between April 1 and August 31.

WEST KOOTENAY AND ARROW LAKES AREA:

The run-off of the Kootenay River at Glade is predicted to be 74 percent of its average or 11,401,000 acre feet between April 1st and the end of August. The Slocan River at Crescent Valley, for the same period, will be near that of an eleven year normal.

COLUMBIA RIVER:

The water content of the snow cover at eleven snow courses varying in elevation from 1800 to 4500 feet is 89 percent of average. The run-off at Golden is estimated at 85 percent of normal or about 1,775,000 acre feet; 90 percent at Revelstoke or 15,947,000 acre feet; and at Trail 93 percent or in the vicinity of 31,618,000 acre feet. A 30-year average has been obtained for the run-off of the Columbia River at Golden, Revelstoke and Trail for the period April 1 to August 31.

The foregoing forecasts are intended to show what may be expected, providing normal conditions relative to temperature and precipitation prevail during the run-off period of April to August, both inclusive.
That is all. There is a tabulation of snow courses filed in the report and I have left a few copies on the table. If there are not enough there, I can send one to any person who wishes one.

Marr: Mr. Frame, we thank you for your excellent report. I should like to make one observation: Along the coast, although low snow is gone, the high snow is intact and is about normal; but as you came to the interior, into the Upper Columbia and the Kootenai, conditions are almost the reverse, there is more low snow there than usual, though not a great deal, at that. The low snow has not melted, but the high snow pack is deficient. Am I correct in that?

Frame: Yes.

Marr: We have with us, as usual, I am glad to say, Mr. Walter Johnson, from the Washington Water Power Company, who will have, I know, his usual excellent report on the conditions in the Spokane and the Chelan basins.

Johnson: It has been my privilege to attend this Annual Forecast Meeting since 1939. For the past several years I have made a few remarks pertaining to snow surveys which I thought would be of interest to you, in addition to giving the results of our annual snow surveys in the Spokane River and Lake Chelan basins.

We have made annual snow surveys for 20 years and have adopted the quantitative method and have a set standard procedure. Within the last 2 years we have made three changes to keep abreast with changing conditions:

1. An annual snow survey made at the end of the accumulation period has been sufficient for our requirements, but this year we made a partial survey in the Chelan area at the end of January. During January indications were that a minimum water year could be expected and we suggested that the Chelan plant be shut down except when required for system peaks in order that we would be assured of a full reservoir this spring and fulfill our part in the Northwest Power Pool. To substantiate this contention the partial survey was made and the plant was shut down. Many of you may recall in January 1936 a similar condition existed at the end of January, then heavy precipitation in February changed the 1936 water year from deficient to good.

2. Of primary importance in the Chelan Basin now is run-off during the filling season and we have shortened our forecast period from April 1 to August 1 instead of April 1 to November 1. By doing this we have increased the accuracy of our forecasts. The error in these forecasts for the 3 minimum years -- 1941, 1929 and 1942, was -7.9%; +4.7%; and -6.1%, respectively. These forecasts are as of April 1 and are not corrected values.

3. A 2-man field party was used in Chelan this year for the first time as we were unable to secure a competent third man. The
chief reason for taking the third man was for an additional safety factor in the event a man would be injured in this remote area. In all our years of snow surveying we have never had an accident.

RESULTS OF 1944 SURVEYS

SPOKANE RIVER:

Water held in snow storage on March 15, 1944 is 40 percent less than 15-year average and is 25 percent more than 1941, our previous minimum year. Forecast natural discharge of the Spokane River at Post Falls for the period March 15 to November 1 is 725,000 s.f.d. which is 2 percent more than actually occurred in 1941, our minimum year.

Our storage capacity in Coeur d'Alene Lake is small and consequently we are assured of a full reservoir each year. Draft from Coeur d'Alene Lake storage may begin about June 15.

LAKE CHELAN:

Water held in snow storage is 30.7 percent less than the 14-year average and is the same as 1941, our minimum year. Results of the survey indicate that it will be necessary to keep the Chelan plant shut down except for time when it is required to carry system peaks until the middle of June in order to be assured of a full reservoir as of July 1. Our results are substantially the same as Mr. Marr's as shown in his April 1 Columbia Basin report.

We propose to keep a close check on precipitation and temperature in this basin this spring in order to modify our forecast to utilize all available water. One foot of Lake Chelan storage represents about $25,000 and you can readily see that the cost of many years of snow surveying pays for itself in one year.

Marr:

I will call on Mr. Criddle, who is my office associate at Boise, to cover the Columbia Basin as a whole and then in addition for the benefit of those who might be interested, he will read from the reports of Montana and Utah, very briefly sketching what the situation is in those states.

WATER SUPPLY CONDITIONS IN COLUMBIA BASIN

Criddle:

Unless compensating rainfall occurs during the coming growing season to make up for the indicated deficiency of run-off from snow cover, approximately 900,000 of the 3,828,000 acres of irrigated land in Columbia Basin will suffer mid-summer and late season water shortage amounting to 25 to 30 percent of the season's supply. Pastures, fruits and late row crops will be most seriously affected. A run-off approximating that of 1931 -- one of the smallest during recent years -- and poorly sustained August and September stream flow are also in prospect.

Irrigated land without first priority water rights, having less than 50 percent of the water needed for this season in storage reservoirs, will be dry by mid-summer according to present
indications. This leaves approximately 24 percent of the irrigated area affected, which is distributed as follows: eastern and northcentral Oregon 125,000 acres, Washington 90,000, Idaho 625,000, and western Montana 50,000.

Below average stream flows are predicted for Columbia River and all of its tributaries. The discharge of the main river at The Dalles, Oregon, is placed at 38 percent below average. The Kootenai is expected to fall short of its average flow by 49 percent, the Clark Fork 46 percent, the Spokane 51 percent, the Clearwater 27 percent, the Salmon 39 percent, and the Snake 43 percent. It is expected also that similar deficiencies will occur in all of the lesser streams.

These predictions are based on the poor snow cover on the watersheds and deficiency of soil moisture in valley soils. Without exception, the depth of water in the snow cover in the higher elevations where most of the run-off originates is 50 to 75 percent below average. The presence in some sections of more foothill snow than usual, due to prevalence of below melting temperatures rather than above normal precipitation at low elevations, is considered insignificant compared to the deficiency at the higher elevations. Compared to past years the snow is poorly packed and averages 5 to 10 percent less in density. Normally this should result in early melting and poorly sustained late season stream flow. The conditions are comparable to those of 1931 in most of Columbia Basin.

The prospects of poor run-off from snow cover are made worse by heavy demand for early irrigation water, which is due to the dry condition of soil in irrigated sections. Unless spring rain relieves this situation, less water can be stored in reservoirs to take care of late season demands than otherwise would be the case. I might say that from April 1 to date, above normal precipitation has occurred quite generally throughout the Basin. Also ground water supplies generally are less than they have been for the past few years, though apparently they are not as deficient as in 1931.

Owing to the lack of precipitation during the past winter and at the beginning of the growing season, feed on the range is poor and soil moisture in the dry farming areas is generally deficient.

Now, I will give some of the snow results and our forecasts of run-off for a few of the major tributaries to the Columbia Basin.

UPPER COLUMBIA RIVER:

The depth of snow water on Columbia River watershed above Birch-bank, B. C. has been measured from 3 to 9 years on 21 courses. On 6 of these, located at elevations ranging from 4800 to 6800 feet, the depth of snow water on April 1, 1944 is 16.8 inches. This compares with an average depth during past years of 24.3 inches, and 17.9 inches in 1941.
The April-September discharge of Columbia River at Birchbank, B.C., for the period 1914 to 1943 averaged 41,420,000 acre feet. The maximum of 49,810,000 acre feet occurred in 1916. The minimum of 31,060,000 occurred in 1926, and was closely approached during the more recent years 1937 and 1941. For the same period this year the forecast, based on snow survey results, is 34,000,000 acre feet.

KOOTENAI RIVER:

The Kootenai, of course, runs back into British Columbia and is tributary to the Columbia above Birchbank, but it is measured at Leonia, Idaho. Snow surveys have been made on this watershed on 11 courses from 5 to 9 years. The April 1, 1944 depth of snow water on 5 of these courses, all located above elevation 4500 feet, averages 16.9 inches, which compares with 25.9 inches average for past years, and 18.9 inches in 1941.

The average April-September yield of Kootenai River watershed above Leonia, Idaho during the past 16 years is 7,416,600 acre feet. The maximum of 10,038,000 acre feet occurred in 1933 and the minimum was 4,722,800 acre feet in 1941. The June months' forecast for 1944, based on the condition of snow cover on the watershed, is 4,000,000 acre feet.

CLARK FORK RIVER:

The Clark Fork River is measured at Heron, Montana. The depth of snow water is measured on 34 courses located generally along the ridges of Bitterroot Mountains and the Continental Divide. Most of these measurements have been made for 7 or 8 years. The April 1, 1944 depth of snow water on 25 of these courses located above 5000 feet elevation averaged 14.4 inches, as against 19.3 inches average for past years, and 11.6 inches in 1941.

The average April-September discharge of Clark Fork River at Heron, Montana for the period 1929 to 1943 is 10,478,500 acre feet. The maximum of 16,126,450 acre feet occurred in 1943 and the minimum was 4,554,200 in 1941. These discharges are not corrected for water diverted to irrigate some 335,000 acres of land and for regulation effected by storage in Flathead Lake and numerous small reservoirs. The flow past Heron during the same period this year is estimated from the mountain snow cover to amount to 5,700,000 acre feet.

CLEARWATER RIVER:

The depth of snow water on Clearwater River watershed has been measured annually on 8 courses for 6 to 7 years. As of April 1 there are 18.6 inches of water in the snow cover on 5 of these courses, which are located at elevations ranging above 5000 feet. The average for past years is 25.1 inches, and in 1941 it was 12.9 inches.

The April-September average natural flow of Clearwater River at Spalding, Idaho during the past 17 years is 7,525,800 acre feet. The maximum for these years was 11,276,900 acre feet in 1945.
The minimum of 4,439,100 acre feet occurred in 1941. Based on condition of this year's snow cover on the watershed, the near minimum of 5,300,000 acre feet is forecasted for the 6 months' period.

**SALMON RIVER:**

The depth of water in the snow cover on April 1 is measured on 10 courses which range in elevation from 5500 to 8870 feet. This year the average depth of snow water on these 10 courses is 15.0 inches. The average for the past 7 years is 20.6 inches, and the smallest of record is 15.0 inches in 1941.

The April-September run-off from Salmon River watershed above Whitebird, Idaho during the past 24 years has averaged 5,656,450 acre feet. The maximum during these years occurred in 1943 and amounted to 9,661,000 acre feet. The minimum of 3,248,000 occurred in 1931. It is forecasted from the April 1 snow cover that the 6 months' run-off this year will be 3,500,000 acre feet.

**SNAKE RIVER AT WEISER, IDAHO:**

The waters of Snake River above Weiser, Idaho are largely used for irrigation and are subject to storage in reservoirs with combined capacity of about 5,800,000 acre feet. The 33 year average river flow at Weiser for the 6 months from April through September without correcting for the upstream use and storage amounts to 7,086,400 acre feet. The maximum during these years was 12,410,000 in 1943. The minimum of slightly more than 3,000,000 acre feet, practically all of which was return flow, occurred in 1924, also in 1931 and 1934. The river flow is forecasted at 3,300,000 acre feet for the 6 months' period this year and this forecast is arrived at by weighing the forecasted flows of the tributary streams.

**LOWER COLUMBIA RIVER:**

An average of 47 percent of the river flow at this station is contributed by Upper Columbia River above Birchbank, B. C., 13 percent by Clark Fork River, 6 percent by the Clearwater, 6 percent by the Salmon and 6 percent by the Snake River. The flow of the Columbia at The Dalles is estimated by weighing proportionately the forecasted discharges of these principal tributaries.

The 65 year average April-September flow of Columbia River near The Dalles, Oregon is 106,170,000 acre feet. The maximum of 173,400,000 occurred in 1894 and the minimum of 56,430,000 in 1926. This year 66,000,000 acre feet is forecasted.

Unless there is some direct interest on the irrigation water supplies on some of the smaller rivers, I will not take the time to read our forecast on those. It is all contained in the report.

I should like to give a few supplemental statements on the water supply outlook for the Columbia Basin and adjacent coastal areas as of April 15. First, with regard to precipitation: as may be indicated by the Boise, Idaho record, the precipitation falling
in Columbia Basin from April 1 to 12 may be considerably above normal generally. This may improve somewhat the water supply outlook for irrigation by delaying the use of stream flow and thereby permitting the storage of additional water. The April 1 to 12 precipitation at Boise, Idaho was 1.39 inches, as against 0.48 inches normal -- 229 percent above normal. Grazing conditions may likewise be improved. On the other hand, it does not appear likely that the run-off will change materially as a result of this extra precipitation.

A little on ground water: ground water supplies are somewhat depleted for this time of the year and may be a negative factor in producing the expected run-off. Since January 1, 1944 stream flow has ranged from 20 to 30 percent below the average for past years. This is partly but not entirely due to delayed run-off from snow cover. Also ground water levels in southwestern Idaho range from 1 to 4 feet below the levels of a year ago.

Something on snow melt: melting of the mountain snow cover appears to be later and less rapid this year than usual. So far there has been very moderate pickup in the stream flow. In southern Idaho during the period April 1-12 the temperature ranged from 30 above normal at Boise to 50 at Pocatello. On April 14 the snow water on one snow course in southwest Idaho at elevation 6400 ft. was 7.5 percent more than the maximum found by weekly measurements during the winter period up to April 1. In other words, snow storms after April 1 increased the snow water content by 7.5 percent at this one course.

SNOW CONDITIONS IN AREAS ADJACENT TO COLUMBIA BASIN

Mr. O. W. Monson of Bozeman, Montana, has prepared the following short summary statement for Montana east of Continental Divide: generally speaking, the situation has improved a great deal since March 1. In the southcentral part of the state, the water content ranged from 90 to 178 percent of the average for the previous 5-year period and fully 30 percent higher than for a corresponding date in 1943. In the central part of the state, the conditions are slightly better than the average of the previous 5 years, although not quite as good as 1943. On the headwaters of the Yellowstone River in Yellowstone Park, the accumulation of water is about 10 percent below the average for the previous 5 years but less than half of the amount stored in the snow cover on April 1, 1943. However, it should be remembered that the snow cover in Yellowstone Park was abnormally heavy in 1943.

Thus the picture in the headwaters of both the Missouri and Yellowstone Rivers is far from dark and if we receive a normal, or slightly above, amount of rain during the spring and early summer, we may expect a normal run-off during the irrigation season. In addition to the rather favorable water supply prospects as shown by April 1 snow surveys, we have about 10 percent more water held in reservoir storage than the average for the past 5 years which fact is still more reassuring.
In a summary of water conditions in the State of Utah, Geo. D. Clyde of the Utah Agricultural Experiment Station reports: there is no critical water shortage expected to develop in any parts of the state but in Cache Valley and to limited extent on the Ogden and Weber Rivers water must be carefully conserved and utilized if the late season's crops are to be saved.

Now, we have a comparison sheet, or graph, showing the amount of snow water held on some of the courses, which we use in the forecast on some of the major drainages. This graph is contained in the water supply report, and I will merely show it on the screen for explanation.

(The graph was here projected on a screen in the front of the room)

This represents the depth of snow water on five courses in the Upper Columbia for the record period and shows what it is in 1944. As you can see, it is not so low as in 1941 or 1942. Five courses on Clark Fork show that the 1944 water content, although not as bad as 1941, is worse than either 1940 or 1942. For two courses in the Yakima River drainage in Washington, 1944 is pretty well down, although not as low as 1941. We have records from 1919 on the Upper Snake River. Most of these courses are located in or near Yellowstone Park, and you will notice that 1944, in that area, is one of the worst years, only 1931 being lower. Finally, for three courses in the Middle Snake River, 1944 is our worst year in the period of record which began in 1934.

Marr: I should like to point out a few things in connection with this presentation. You will recall that Mr. Frame forecast Columbia at Birchbank as very close to 32,000,000, and we forecast 34,000,000.

Frame: You take from April to September. I take from April to August.

Marr: Oh, I see. I didn't catch that. Well, then, that explains the difference, the two might be very close together.

Frame: I made the comparison. They are not far apart.

Marr: Just as a follow-up, I should like to tell you how some of our forecasts came out last year. This year is quite similar to last year in that we are dealing with extremes. Last year we were forecasting a tremendous run-off, more, in some cases, than the 40-year record, and this year we are forecasting a very low record. We forecast last year 41,000,000 acre feet for the 6-months' run-off at Birchbank, B. C. There were 38,518,000 acre feet passed Birchbank, B. C. That is 6.4 percent error.

As to the Columbia River at The Dalles, we forecast 105,000,000 acre feet. There were 112,591,000 acre feet. That is a 6.7 percent error. The errors in some instances were more owing to the lack of comparable data for past years with which to establish the upper reaches of forecast curves. However, most of our 1943 forecasts were very good, considering the fact that we were forecasting an unprecedented run-off. I hope this year we will be as
accurate, although I want to warn that during a low year a forecast can be upset very easily because above normal rainfall can add quite a bit to a small run-off, and our percentage of error might be larger than we would like to have it.

I want to call on Mr. Veatch now for his story about the snow cover along the Pacific Coast area in Washington. Mr. Veatch took charge of the snow surveys in this area beginning this year and has carried them on most excellently.

Six snow courses are maintained in the Skagit River Basin in cooperation with the City of Seattle. The densities in that area have been about 30 to 33 percent this year. We have only one year of record and, therefore, cannot compare the snow depths with any other year.

In the White River Basin 6 courses are maintained in cooperation with the Seattle District Office of the Army Engineers. There the densities are surprisingly higher, being about 39 or 40 percent at all of the higher courses. In the White River Basin there are 5 years of record at most of the snow courses and those years range as follows: 1943, of course, was the highest. 1942 and 1944 are almost exactly equal and follow in second place in that 5-year period. 1940 is next to the lowest, there being no information at two courses in that year. 1941 is the lowest. 1944 snow depths in percent of the 5-year average range from 61 percent to 90 percent, with an average of 75 percent.

In the Lewis and White Salmon River basins in Southern Washington, 4 courses are maintained in cooperation with the Pacific Power and Light Company. There the snow densities are also higher than have been indicated to be present over the Northwest in general. On the eastern and southern slopes of Mt. St. Helens, the densities were 43 and 44 percent respectively on 2 snow courses. On the Divide between the White Salmon and Lewis River basins, the densities were 35 and 36 percent.

I have no further remarks unless there are some questions.

We will probably hear more from Mr. Veatch a little later on in connection with other matters. We will learn to pay a good bit of attention to Mr. Veatch's reports from now on because he will begin to accumulate very important data for the coastal area, and will be able to give more of a story as his record is lengthened.

Now, we are going to give Mr. Work his chance at forecasting. We haven't heard very much from Mr. Work, and we usually have a fine report from him, so we will give Mr. Work all of the time he wants to tell the story about Oregon.

I don't have any prepared discussion so my remarks will be based on this little colored map issued in our Oregon snow report this year. (pointing to projected image) The areas which are colored green are those in which we believe the water supply will be adequate for the production of crops on the usual acreage. The
areas colored orange are areas in which we believe the water supply generally will be adequate but will likely be short late in the season, and some decrease is expected in crop production on the usual acreage. This large crimson-colored area is an area of prospective deficient run-off; the little green areas interspersed in this large crimson blotch are areas served from storage.

We might put the Oregon picture in this way: lands served from storage reservoirs generally will have an adequate water supply. Most of the lands depending upon unregulated run-off will have a water supply ranging from a moderate shortage to a rather critical shortage.

Starting up here in the area near The Dalles and working east, I might say that the wheat lands in Sherman, Gilliam and Morrow counties and over in Umatilla County have quite a fair soil moisture supply, particularly those lands which were fallow last year. There has been a good hold-over of soil moisture from last year, and although bumper wheat production is not expected, production should be at least average.

McKay reservoir should at least three-quarters fill. Cold Springs reservoir is full. That will insure a good water supply for several thousand acres down in the Westland and Hermiston districts. The other small tributaries on the Umatilla, such as Birch Creek and Butter Creek, are expected to have a short flow late and without alleviating rains there will probably be a considerable decrease in production of alfalfa hay.

One of the areas of most critical shortage in the State appears to be the extreme northeastern corner of Oregon. Flows of those small streams such as Hurricane Creek, East Fork of the Wallowa, Bear Creek, and so forth, apparently will be the least since 1926 and are expected to be even lower than in 1930, 1931 or 1934. Of course, as Mr. Harr pointed out, precipitation during April, May and June can do much to change this picture. We hope it will for the sake of the people producing crops in that area.

It may interest you, Mr. Breithaupt, to learn that we estimate in the three counties of Wallowa, Union, and Baker a possible reduction of 47,000 tons in alfalfa and wild meadow hay due to water shortage. In Baker County about the only area that looks very good is the 7,000 acres or so served from Thief Valley reservoir. That reservoir is full.

Coming on down to Burnt River, some 11,000 acres served by Unity reservoir have a good water supply in sight; otherwise, deficient. The same thing holds true down here on the Malheur and Owyhee. Owyhee reservoir probably will not fill this year for the first time in several years. Warmsprings reservoir probably will not fill. Agency Valley reservoir probably will fill. Unity reservoir probably will not, but should nearly fill. For those of you interested in possible contributions of water from Oregon to the Snake, the significance of this outline seems to be that there won't be much contribution from Oregon, because whatever there is will be held in these reservoirs.
I am informed that Malheur County is populated with about one percent of the cattle population of the United States. Mr. Breithaupt can check me on that. Consequently, the matter of feed supply is pretty important to those people. Down in the south end of Malheur County the water supply, apparently, will be very short. Antelope reservoir, with storage capacity of 36,500 acre feet, will be fortunate to obtain 10,000 acre feet storage this year.

Coming over to Harney Basin, the run-off of the Silvies River is expected to be about a third of normal. Over on Crooked River, last year's inflow to Ochoco reservoir was forecast as about 200 percent of normal, and that was obtained. This year we are forecasting it at 9 percent of last year. I hope they get more than that, but it doesn't seem to be in sight.

A Member: What percent?
Work: 9 percent.
A Member: N-i-n-e?
Work: Yes. We judge that will give them 27,000 acre feet supply this year. There have been 10 previous years in the history of that project when their supply was 27,000 acre feet or less. It is significant to note that in only one of those 10 years was there any water remaining in the reservoir after August 31. The chances are that this project will not have any water remaining for irrigation after the latter part of August unless we have unusually heavy early summer rains which will permit them to withhold that water and not turn it out of storage until later in the season.

Over in the Deschutes Basin the outlook is really quite favorable. Crane Prairie reservoir should peak at about 50,000 acre feet; Crescent Lake reservoir is now full to the capacity limited by an agreement with the Southern Pacific Railroad, and they are now actually by-passing water, so this rather large area of crop land irrigated from those reservoirs is going to be in good shape, and no doubt they will have a fairly substantial hold-over at the conclusion of this irrigation season.

Conditions in the southern part of the State have no bearing on the Columbia, but some of you may be interested in the outlook down there. In Jackson County, lands served by the Medford and Talent irrigation districts have quite a fair water supply in sight due to the hold-over in their reservoirs. The Talent District is likely to withdraw all of their storage, but Medford and Rogue River districts should have a stored nest egg at the completion of this season. The Grants Pass Irrigation District, in Josephine County, can expect canal alternation, due to a low stage of Rogue River, by about July 15. If this condition comes to pass as predicted, it will be the earliest date for such canal alternation since 1934. Over on the Klamath side, of course, there is so much water in storage in Upper Klamath Lake and in Garbor and Cleor Lake reservoirs that there will be an ample water supply for lands served from those sources.
If there are any questions on this, perhaps I can answer them while we have the map here.

Breithaupt: On the claimed shortage up in the northeast corner, how many hay-growing counties are involved in that, Work?

Work: Several hay-growing counties are involved. In Wasco County we didn't get a figure as to gross reduction. The estimate arrived at there was reduction of 10 percent of their usual tonnage. Unfortunately, I don't know what their usual tonnage is. In Umatilla County, reduction of about 2,500 tons. Union, Wallowa and Baker counties combined, 47,000 tons. Malheur County -- well, I have those figures. I will give them to you later in your section. An estimate for the State as a whole over in these hay-growing counties is about 100,000 tons.

Breithaupt: Thank you.

Work: Any other questions?

Nielsen: Mr. Work, in those three counties of Wallowa, Union and Baker, that 47,000 tons that you refer to refers to alfalfa hay, does it not?

Work: Principally, yes.

Nielsen: Well, if that is true -- and, mind you, I am not disputing you -- the situation of those three counties is quite alarming, isn't it?

Work: I should say so.

Nielsen: In 1934 it is my recollection that the census showed about 134,000 acre tons of alfalfa, and in 1939 about 150,000. Now, if you are going to have a 47,000-ton drop in those three counties, it would seem to me you have a rather critical condition.

Work: Well, here is what leads us to think that is in the cards. We are forecasting the flow of the Powder River at Salisbury. That is our key station, there, as an index to the water supply of that valley. It is unfortunate that gaging stations do not exist on some of the other streams which furnish water. For instance, Rock Creek, quite an important little stream, has no gaging station. The North Powder has no gaging station. Eagle and Pine Creeks have no gaging stations. You understand it is not possible to correlate snow data with run-off unless you have some key to the volume of water that was produced. But anyway, we do have this station on Powder River at Salisbury. We are setting the run-off there this year at 21,000 acre feet for April-September, which is about 30 percent normal for the period 1904-1943, with the exception of a break in the record. With the exception of the year 1934, we believe it likely to be the least recorded since 1904, except for this period of broken record.

In Baker County there are about 93,000 acres of irrigated land served by Powder River and its tributaries. The water supply appears "good" for only 7,000 acres out of 93,000 or 94,000 -- whatever that exact figure is; and with a water supply only 30 percent normal, it seems that unless spring rains come to the rescue there is bound to be a heavy reduction in hay production.
So far as the reduction in production of potatoes is concerned, we think that may not be so serious because those farmers growing potatoes usually have special watering facilities — wells, and so forth.

Marr: In a year like this it is quite important to determine as much as we can about ground water contribution. I am glad to see that Mr. Phillips will have something of interest to us in this connection with regards to stream flow. Mr. Phillips, am I right about this?

Phillips: It was somewhat of a shock to me, Mr. Chairman, to learn a couple of days ago upon receiving the tentative outline of the agenda for this meeting, that I was supposed to discuss river flow in past years and the reasons therefor. That is a rather broad subject, "the reasons therefor." Ordinarily the Geological Survey doesn't go into that, and I have made no study of it. I can only say that the flow of any stream is merely an integration of the run-off producing factors — rainfall and snowfall, the seasonal swing of temperature, soil and geology, the activities of man, and vegetative cover. For a large stream like the Columbia the flow is, of course, an integration of many hundreds of small streams, so that "the reasons therefor" might be quite complicated.

Every year at this meeting while you other gentlemen are looking forward expectantly to a flow for the next 6 months it seems to be my lot to look backwards, somewhat in the fashion of the fabulous Filly-loo bird, which is supposed to fly backwards because he is so keenly interested in where he has been. I don't mean to say that I am not interested in where we are going or in the expected stream flow, but sometimes a back-sight is helpful in prolonging a line, so I have been asked to make a few comments on stream flow in past years, for what they may be worth.

In that connection, I think we might take a few minutes to consider the so-called index stations in Oregon. For the last three years the Geological Survey has issued a monthly Water Resources Review; many of you, no doubt, receive it. The Oregon District of the Survey contributes records for the Columbia River at The Dalles, Umpqua River at Elkton, and John Day River at Service Creek. The Umpqua River, as you know, is immediately south of the Willamette Basin in West Central Oregon and was chosen because it represented an area which could not possibly be represented approximately by the records from any other Geological Survey District. The John Day station is at Service Creek below the North Fork of the John Day and includes all large tributaries; its drainage area is 5,090 square miles. The Columbia River at The Dalles has its gaging station at Celilo Falls, with a drainage area of 237,000 square miles.

For the record, in 1942-43 the Umpqua River at Elkton had a run-off of 41.4 inches over the drainage basin, the drainage there being 3,680 square miles. This is the second largest run-off of our record, which began in October, 1905, the greatest being 44.67 inches in 1921.
During the water year ending September 30, 1943, every month was above normal except October, March and May, the total of the year being 63 percent above the normal for the entire period of record. That summer's excess carried over through October last, and rains in November produced sufficient run-off so that those two months were above normal. December 1943 to March 1944 have been well below normal, so that for the 6 months just passed the total run-off has been 10.7 inches, which is 60 percent of the long-time normal and only 32 percent of the run-off during the same period of last year. Where I speak of "normal" for these various streams, the periods of record vary, and for that reason there may be some slight lack of agreement with percentages. Because this figure seemed quite low, one of the lowest on record for the Umpqua River, similar data were computed for the Willamette River at Albany, the station having the longest record within the Willamette Basin. It is not one of our index stations. The drainage area here is 4,840 square miles, with continuous record since October 1895, a period of 48 years. From October 1 to March 31, of 1943-44, the run-off has been 3,990,000 acre feet, -- round it off to 4,000,000 if you wish, -- 15.5 inches on the drainage basin. This is 59 percent of the long-time average for that station. We have only a 38-year period on the Umpqua, but the percentage of normal is very nearly the same: 59 percent for the Willamette; 60 percent for the Umpqua.

A year ago in the 1943 water year, we had numerous serious floods on the Willamette River, one of them particularly damaging. This year there has been no stage which could properly be called a flood. The maximum discharge was reached November 6, when the stage at Albany was 13 feet and the corresponding discharge 46,300 second feet. That is only 22 percent of the maximum discharge reached January 2, 1943 (218,000 second feet). That maximum of 46,300 may yet be exceeded. Twice in the record period the maximum for the year occurred rather late. In April, 1937, the maximum for the year was 127,000 second feet, April 16. In 1933 a maximum was reached June 11 considerably higher than we have so far had, but it did not happen to be the maximum for that year. There may yet, therefore, be floods greater than the small one of last November.

For the station on John Day River, which drains 5,090 square miles of Central Oregon, largely the Blue Mountain area, the record is continuous since 1929. This is a shorter period and perhaps a drier cycle than represented by the Umpqua or Willamette records. At any rate it includes more years of low run-off in general. The water year 1942-43 was the greatest run-off year of record by a considerable margin. 1944 so far has been one of the lowest. The run-off for the period October 1 to March 31 of this year is 239,000 acre feet, which is 67 percent of the median flow for that station; it is only 26 percent of the flow for the corresponding period of last year. This in spite of the fact that throughout October and November and even December the flow at the station was above normal, perhaps because of a sort of hydrologic momentum due to the fact that the flow for nearly all of last year was far above normal. That carried over into the current year. To some
extent, at least, that carry-over last fall represented a rather high ground water condition.

In the Umpqua and the Willamette, the peak flows and the majority of the run-off occurs during the period November 15 to March 31. Nearly all of the peak flows have occurred within that period. On the John Day, the peak flow customarily comes in April or May, owing to melting snow in the Blue Mountains.

On the Columbia, however, we have a different condition, and nearly all of the peaks have come within May or June. The earliest peak came May 2, in 1934, a discharge of 453,000 second feet. The latest was in 1880, when it reached a peak of 914,000 second feet on the 30th of June, and that continued to the 2d of July. That is the only ----

Canfield: May I interrupt? That part relating to the Columbia River I believe should be presented later. Mr. Marr was calling on you for a summary of run-off, October to April, on Oregon streams other than the Columbia River, ----

Phillips: Oh, I see. I will be glad to postpone it.

Canfield: ---- and we want that figure of percentage of run-off for the first 6 months of the current year. I believe we should reserve your statement on the Columbia River until later.

Phillips: That is quite all right.

Marr: Mr. Phillips, we thank you for that splendid interpretation of the early stream flow.

Mr. Criddle and I, not knowing that Mr. Newell would be here, gave a little information of the same sort for Idaho. I wonder whether Mr. Newell would care to make a further comment about the stream flow last fall in Idaho. We showed from the current stream flows of Salmon River and Boise River that the stream flow during the fall was somewhat above normal. The heavy run-off for 1943 carried through until about the first of the year, and after that time fell below normal. Would you care to tell us of your observations along this line, Mr. Newell?

Newell: Gentlemen: I think Mr. Marr intends just to introduce me to this crowd. My background is Upper Snake River in Idaho, and what he has said about our key station, the Salmon River at Whitebird, I can confirm. I might state in general, - Spring is late. I was in the Kootenai Valley a few days ago. At elevation 1,750 there were two feet of frost in the ground on the west side; rangeland dried up. Pretty late to have two feet of frost in the ground at that elevation.

I came down past the Clearwater River, one of our steepest rivers, the one that kicks the hardest early in the spring, but when we went to it to see if there is any real snow supply back there, we found it not kicking very hard this spring.

I came on down, as I was somewhat worried about Owyhee reservoir. It is over in Mr. Work's territory. I was interested in hearing
his comment that the Owyhee will probably not fill. I don't believe the Owyhee will fill. I called on R. Jain several days ago to see if he had extra water at the plant which might be available for power purposes, and possibly do some pumping onto the Owyhee project to conserve for next year water supplies now stored in Owyhee reservoir.

Last night late I came in by train through the Union County section along the Powder River. It looks pretty sorry for this time of year. I think perhaps Mr. Work may be right. There may be a very serious reduction in the amount of forage that can be grown in that valley this year.

I am interested in irrigation water supply in Idaho, and I came here to hear what you people have to say. I thank you.

Marr: Mr. Newell brought out an important point: in certain parts of the Columbia Basin the frost isn't out of the ground in the low reaches, and also what little snow exists there hasn't melted, so that may in part account for the low stream flow since the first of the year.

Is Mr. Piper here? (Pause) Well, we will have to omit the next section, then. We had Mr. Piper scheduled to talk on ground water. Our section, I think, is complete, Mr. Work.

Work: Mr. Phillips' statement was most interesting -- I can't give his exact wording, but Mr. Phillips inferred rather plainly that the run-off momentum due to restored ground water in 1943, which we hoped would continue into this dry year and help us out, is gone.

Phillips: I dislike to say anything with respect to ground water, because I don't know much about it, but that would be my interpretation if I had to give one.

Work: There was more discussion on that point, I believe, this year, in the Oregon Forecast committees than on any other single point. It was the one thing committee members were not entirely agreed upon. Some of our committee men, in the belief that the accumulation of ground water due to the very heavy snow supplies and very heavy precipitation last year would carry us through, were inclined to set the flow of the Malheur River and the Silvies River at a very much higher stage for April-September than I was inclined to set it. That is a very important point and one on which we need more information. Has anyone else any observations or any data which will help us to pin that factor down?

Phillips: I could add just a little to what I said a moment ago. It may be that there are locations where the momentum may be continuing. I am thinking now of the Deschutes Basin, particularly, where there is a very deep, porous soil cover, and the effect of a single year's heavy snowfall may carry over for as much as 12 months. That is just a guess on my part, but I think it is not far out of line when you consider how steady some of those streams are in an exceedingly dry year, as we have had occasion to notice in 1926, 1930, and 1934.
Canfield: Mr. Chairman, I believe also in the Deschutes Basin there is a very porous geologic structure below the ground which leads to conserving of precipitation for later run-off. In your review of the situation in Oregon, you spoke of the rather good supply for the Deschutes, and I believe this is one of the reasons: part of the water which fell as precipitation last year is carried over into the slow release through springs.

Work: Well, yes. For instance, in the Crescent Lake net inflow forecast for 1944, we are crediting the snow cover of last year with 45 percent of the probable inflow of this year; but even so, giving last year's abnormally heavy snow cover a credit of 45 percent, it still sets the 1944 probable inflow at 63 percent of normal, the deficiency of this year is so great.

Jackman: With what former year do you compare this year?

Work: In Oregon?

Jackman: Yes.

Work: Well, it isn't uniform, Mr. Jackman. In extreme Northeastern Oregon, it compares with 1926. On the Powder River it compares with 1930 and 1931. That is true, also, on the Malheur River. On the Walla Walla and Umatilla Rivers it is much better than those years, apparently; and on other streams it compares with 1941. In 1941, you may recall, we were putting out a pretty dire prediction. Fortunately, summer rainfall in some parts of Oregon was 300 to 400 percent normal during the period April, May, and June, and it had the effect of turning what would otherwise have been a critical water year into a fairly good water year; but it did not necessarily have the effect of materially altering the stream flow forecasts. The beneficial effect of the rains came in this way, and this is the way it could come this year, as I see it: in reducing the demand for irrigation water.

We will go right ahead, then, gentlemen, into the section of discussion to be led by Mr. Canfield.

Canfield: The situation this year relative to the probable peak of discharge of the Columbia River and the run-off is certainly different from that of a year ago. Shortly after Mr. Marr arrived last evening, in talking over the 'phone, we agreed that on February first a year ago it was very evident there was going to be a year of large run-off. But this year on February first the reverse was true: it was very evident that it would be a low year.

As regards the discharge of the Columbia River, details will be presented by Mr. Phillips, my principal assistant in the Portland District of the Geological Survey. A year ago on this date the discharge of the Columbia River was 391,000 second feet. Today it is about a fourth of that, 111,000 second feet. Our forecast of peak discharge a year ago was not too close to what actually occurred, as many of you will recall. The average of several estimates was 673,000 second feet, but the actual
recorded peak was 546,000 second feet. I think, now, we had better see if we can arrive at an estimate of this year's peak discharge of the Columbia River and also the run-off for the 6-months' period April 1 to September 30. We have already had one forecast of the run-off for that period by Mr. Marr: 66,000,000 acre feet.

First, we should have a review by Mr. Phillips and Mr. Veatch of the run-off conditions of a year ago and the run-off this year to the time of this meeting. Therefore, Mr. Phillips, I will call on you again. I am sorry I interrupted you before, but I didn't want to have you take any of the thunder from this section and give it to Mr. Marr's section.

Phillips: Resuming as nearly as possible, where I was, the peak discharge on the Columbia River at The Dalles has varied from May 2 to July 1 over a period of 65 years. The average date has been June 8. In general, I think it may be said that the larger peaks come later than the smaller peaks. There are many exceptions to that, however. Certainly the earliest peak was a rather small one; the latest peak was the second highest of record, which as I mentioned occurred in 1880. However, the maximum peak of record occurred June 6, practically the average date, in 1894: 1,170,000 second feet. The smallest peak of record was 269,000 second feet in 1926, and it was one of the earliest, occurring on May 8 and 9.

Last year there were a number of sharp rises each followed by a slight recession and another rise, the first one coming in April, others in May and June, the actual peak being recorded June 21: 546,000 second feet at the station near The Dalles. Some of you are more interested in the flow at Cascade Locks or Bonneville. The discharge at Cascade Locks on that date would have been about 552,000 second feet. The peak could easily have been higher in the first week of July last year if meteorological conditions had shaped themselves up just right. A good warm rain about that time would have brought out enough more snow to have caused a peak the first week in July, higher than that actually recorded and perhaps the latest, or one of the latest, of record.

Last year at the end of March the run-off for the 6-months' period was 37,500,000 acre feet. The total for the year was just four times that: slightly over 150,000,000, and if we add to that total at The Dalles the inflow from Hood River, White Salmon, Wind River, Klickitat and other unmeasured tributaries, the total run-off for the year at Cascade Locks would be 155,000,000 or 156,000,000 acre feet, which is so close to an exact check that we may give Mr. Wahle of the Bonneville Administration credit for an exact forecast of that value at our meeting here last year. He predicted 155,000,000 acre feet at Cascade Locks for the year. The run-off for the first 6 months this year is 29,950,000 acre feet. A part of this has come from the release of storage in Grand Coulee reservoir. Disregarding that factor of storage release for the moment, the run-off for the
A year ago at this meeting there was considerable discussion of the effect of storage in Columbia River reservoir, above Grand Coulee Dam, on the 1942 river peak. Mr. Veatch, District Engineer of the Geological Survey at Tacoma, gave us facts showing the correction due to storage in that reservoir. At this time I will ask Mr. Veatch to give us information relative to the discharge of the Upper Columbia River a year ago and during the first 6 months of the current water year, and the effect of Grand Coulee storage.

Veatch:
The effect of storage in Columbia River reservoir on 1943 crest discharges downstream from Grand Coulee Dam, and some observations regarding 1944 conditions:

The 1943 crest stage of Columbia River near The Dalles, Oregon, was not affected by storage behind Grand Coulee Dam, because this peak occurred several weeks after the Columbia River reservoir was filled. It resulted from a secondary peak stage of the Snake River coinciding with a secondary crest stage of the Columbia River at Trinidad, which is below Grand Coulee Dam. Although the Columbia River at the International Boundary did not reach its highest discharge until July 6, most of the river below Grand Coulee Dam crested in June due to the addition of high run-off from the tributaries.

A year ago on this date the Columbia River reservoir lacked only about 300,000 acre feet of being full, whereas now it is 2,100,000 acre feet below capacity. This is equal to about 1,050,000 second-foot days or 50,000 second feet for 21 days. If the reservoir is filled as rapidly as possible, it should be full several days before the crest stage of the year. Therefore, it seems likely that this year's peak discharge at The Dalles will not be affected by storage.

I have a graph which I would like to have run on the machine. These (pointing) are hydrographs of daily discharge from March through September, 1943. The white lines represent the 1943 records of the Columbia River, starting with this dashed line for the International Boundary, then this pin-dotted line for the outflow below Grand Coulee Dam, and the white line which follows close to that is the Columbia River near Trinidad, Washington, which is very similar in discharge to that of Grand Coulee Dam. The upper white line represents the Columbia River at The Dalles. The Snake River at Clarkston, Washington, is also represented by this line crossing the others. Shown as a solid black line is the 1944 river discharge at The Dalles from
HYDROGRAPH FOR COLUMBIA RIVER & SNAKE RIVER 1943

Note: All graphs are for 1943, unless otherwise indicated.

Capacity Table for Columbia River Reservoir:

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U.S. Geological Survey
TACOMA, WASH.
APRIL 14, 1944
March 1 to date. A year ago, as you can see, the flow at The Dalles was nearly 400,000 second feet, whereas, today, it is only about 110,000 second feet.

The same sort of comparison holds true for the inflow into the Columbia River reservoir in 1943, the record of which for the Columbia River at the boundary is shown by this dashed white line. The daily estimated inflow for 1944, plotted here in dashed black, is the boundary record plus the Spokane River and other small tributaries. That information has been furnished by the Bureau of Reclamation and is based on the discharge below Grand Coulee Dam corrected for storage through a day-by-day subtraction of the reservoir stages, and does not represent an actual stream flow record above the reservoir. There would be small fluctuations due to wind effect, and so on (indicating throughout on graph). On June 21 last year the discharge at The Dalles was at its crest. That was the result of this crest on the Snake River, and this little crest on the Columbia near Trinidad (pointing). The Columbia at the International Boundary did not have its crest discharge until the second week in July, but as you go farther downstream the crest came earlier because of the addition of tributary inflow.

Now, because the inflow and outflow graphs of the Columbia River reservoir are nearly parallel, it shows there was little or no storage effect behind Grand Coulee Dam, after late May last year. What little storage effect there was occurred earlier in the season. Elevation 1290 represents a full reservoir, and this was nearly reached by May 25 last year. Today the reservoir is at about elevation 1262, or 28 feet below its capacity. The capacity at today's stage is about seven and a half million acre feet, whereas when full, the reservoir holds 9,650,000 acre feet. It is possible to hold back 50,000 second feet constantly for 21 days before the reservoir will be full. However, discharge of the Columbia is so large that there is every reason to believe that the reservoir will be full this year before the natural crest discharge occurs, in which case the full crest should pass through Grand Coulee Dam without storage effect. It is possible that an arrangement might be made to hold up a little of the crest in the interests of flood control if it appears that there is going to be an unusually high crest discharge, but I think we could fairly safely count on the natural flow reaching The Dalles this year.

Canfield: The next gentleman on the program is Mr. Banks of the Bureau of Reclamation, who is represented here today by Mr. C. P. Christensen, who will give us information relative to the proposed operation of the Columbia River reservoir during the current year.

Christensen: I have a memorandum here that was prepared to give some indication of the use that has been made of the Columbia River reservoir this year and the rate at which it is proposed to fill, and this is accompanied by a sketch. This is the first year in which we have had experience in filling the reservoir, so we may miss it some.
Reference is made to the accompanying print of drawing L2-3877 which delineates in black, the reservoir stage, inflow, turbine discharge and total discharge as based on observed data from November 1, 1943 to the present date, (April 14). Shown in colored crayon are estimated reservoir stage curves and pertinent flow curves for the subsequent refilling period.

Briefly, the drawdown period may be summarized as follows: Drawdown began from elevation 1290, November 1, 1943 and continued at an intermittent rate to elevation 1259.3 on April 5, 1944 for a total drop of 30.7 feet or a total storage loss of 2,320,000 acre feet. The drop from elevation 1290 to 1287.6 was made to facilitate maintenance operations on the spillway face of the dam and in the tailbay and amounted to 195,000 acre feet. All subsequent lowering was made to provide the storage spilled at the request of the Bonneville Power Administration and the storage used through the Coulee Power Plant. The quantities involved were 1,706,000 acre feet spilled to the Bonneville Power Administration and 419,000 acre feet used through the Coulee Power Plant.

Except for a minor instance in the winter of 1942-43, this season required the first large withdrawal of Coulee storage for power purposes since the dam was completed. The natural inflow, although low, (10,192,000 acre feet from November 1, 1943 to April 1, 1944), was well above the inflow for the critically low corresponding season of 1936-37 when it amounted to about 6,720,000 acre feet. This latter figure, however, does not of course reflect the storage subsequently added to Flathead Lake for winter release, which would now materially increase the inflow under the same conditions.

Beginning April 6 the reservoir started refilling and has risen to elevation 1261 as of April 14. In preparing an estimate for the completion of the refilling, two schedules were computed. One was based on the 28-year average inflow and is shown in blue crayon on the print. The other was based on a 3-year average, 1929 to 1931, (which were consecutive low run-off years), and is shown in red crayon. Both schedules were computed assuming the total discharge is to be held to 35,000 c.f.s. until a daily increase in the discharge of not over 7,500 c.f.s. is required to equal the assumed inflow on the day the reservoir is filled. In an average year the daily rate of increase has been about 5,000 c.f.s.; however, there are several instances when this rate has exceeded 12,000 c.f.s. per day for several continuous days and in years when the total flood peak did not exceed about 300,000 c.f.s.

A summary of the estimated schedules is as follows:

<table>
<thead>
<tr>
<th>Inflow</th>
<th>Date Discharge Begins Rising</th>
<th>Reservoir Elev. on Date Disch. Begins Rising</th>
<th>Date Reservoir is Filled</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-yr. Avg.</td>
<td>April 23</td>
<td>1273.0</td>
<td>May 12</td>
</tr>
<tr>
<td>1929-31 Avg.</td>
<td>May 2</td>
<td>1276.0</td>
<td>May 27</td>
</tr>
</tbody>
</table>

Based on information now available it is believed the actual refilling program can be maintained within the approximate limits of the above schedules.
Canfield: If the reservoir fills early in May, by May 12, there probably will be little effect of storage in Grand Coulee reservoir on the peak discharge. If it is as late as May 27, and the peak as indicated by Mr. Phillips for a low year occurs early in May, there may be some correction for storage.

Mr. Christensen, do you have any information as to the amount of water released from storage in Kootenai Lake? I understand the Lake was drawn down two feet more than usual this year and I am wondering if you have any information on that.

Christensen: No, Mr. Canfield, I do not.

Canfield: Possibly Mr. Webb has. If I may, I would like to arrive at, if I may, a correction to the observed flow at The Dalles for the first 6 months of the water year by Coulee storage of approximately 2,000,000 acre feet, and Kootenai Lake storage, and then have Mr. Phillips give us a percentage in relation to the median for the first 6 months. Mr. Webb, do you know what the storage release has been, a million acre feet, or some such value?

Webb: Mr. Canfield, I haven't with me exact figures on the release of stored water from Kootenai Lake. This would have been quite a low water year under normal conditions. The discharge from Kootenai Lake throughout the winter months has been maintained at possibly between 7,000 and 8,000 second feet. Without storage it is quite possible that the flow out of Kootenai Lake might have dropped as low as 4,000 to 4,500 second feet. I don't know whether that would be helpful or not, but I have no data other than that with me.

Canfield: Mr. Phillips, you gave us for Oregon certain percentages for Willamette River at Albany, Umpqua at Elkton and John Day, which varied between 59 and 67 percent. For the Columbia River, if one corrects by 2,000,000 acre feet, can you give us a relation to the median?

Phillips: It would be very nearly 75 percent.

Canfield: It is more, then, than the other percentages for Oregon streams?

Phillips: Yes; it is distinctly more. It would be 75 percent, I think.

Canfield: I believe now we have completed review of the past so we will proceed to what may be expected in the future. At this point we usually introduce Mr. Wells of the Weather Bureau. Unfortunately, he is ill and will not be able to be here today. I am sure he would have liked to have been here. I recall that last year he commented that he had been studying this thing for 25 years and it was very pleasing to him to see so many people present interested in this matter of the peak stage of the Columbia River. But Mr. Ashton Codd is here representing the Weather Bureau, and I am sure he will give us something.

Codd: We are very sorry that Mr. Wells was not able to come and give us a summary of the weather conditions, and we were so sure that he would be here that last night when we left the office I didn't...
even pick up a copy of his summary of weather conditions over the past winter season, and, as a result, it is still there in his office. But I am sure we all know what the weather conditions have been, and I won't attempt to summarize them. We are publishing the weather summary in our snow bulletin that comes out with the March Climatological Data, and I am sure that you are all subscribers to that Weather Bureau publication and will receive a copy of this year's data. We are also including with that publication our figures on the forecast of the Columbia River and tributaries.

I have the pleasure of introducing Weather Bureau River District Officials from the three river districts covering the Columbia River and its tributaries. Mr. Robert B. McComb, of our Spokane office; Mr. George F. Von Eschen, of our Boise office; and Mr. Elmer Fisher of our Portland office. I would like to take this opportunity of introducing Mr. Ray K. Linsley from the Sacramento River District office. Mr. Linsley has been with us for the past few days, assisting in the preparation of the forecasts to be presented by the Weather Bureau. Without his guidance, I am sure the forecasts would not be as complete as we have prepared them.

In October of 1943, the Weather Bureau divided the large Portland River District, which covered the entire Columbia River Basin, into three smaller districts, creating the Spokane and Boise Districts. The Spokane District covers the Upper Columbia River, and tributaries downstream to Grand Coulee Dam. The Boise District covers the Snake River down to Lewiston, Idaho. The Portland District covers the Middle and Lower Columbia River, the Willamette River, and coastal streams. In presenting our forecast this year, I would like to preserve the identity of those districts, by first presenting the forecasts for the Spokane District, and then those for the Boise District.

A word of explanation at this point may be in order, to demonstrate the statistical and graphical methods of deriving the following estimates of seasonal run-off. Let us take for an example the upper Flathead River Basin, where five precipitation stations were selected, whose records were comparable to the length of stream flow record at Columbia Falls. The December to March seasonal totals of precipitation at these stations were computed for the years of record. The average seasonal precipitation of these five stations was plotted against the April-July seasonal run-off at Columbia Falls. Although there was considerable scatter to these points, a smooth average curve was drawn through them. The deviations of the plotted points from the curve were next plotted, using the 5-station average of October-November precipitation as the second variable. Through a process of "Successive Approximations" the original curve was corrected for antecedent conditions affecting the correlation between precipitation and run-off. Correction curves for these variables are shown on the graphs where necessary. A simple graphical process of routing this estimated seasonal flow from station to station was used to bring the water downstream to junctions of major tributaries where they were combined and projected to the next station below. Similar computations and graphs were prepared for all major contributing streams.
The following predictions of April-July run-off are given as the Weather Bureau's contribution to this committee:

<table>
<thead>
<tr>
<th>Expected Run-off Volumes</th>
<th>April-July</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spokane District</strong></td>
<td></td>
</tr>
<tr>
<td>Flathead River at Columbia Falls</td>
<td>1,750,000</td>
</tr>
<tr>
<td>Clark Fork River below Missoula</td>
<td>3,100,000</td>
</tr>
<tr>
<td>Clark Fork River near Plains</td>
<td>2,800,000</td>
</tr>
<tr>
<td>Clark Fork River near Heron</td>
<td>3,400,000</td>
</tr>
<tr>
<td>Pend Oreille River at Priest River</td>
<td>4,600,000</td>
</tr>
<tr>
<td>Pend Oreille River below Z-Canyon</td>
<td>5,000,000</td>
</tr>
<tr>
<td>Columbia River at Birchbank</td>
<td>21,100,000</td>
</tr>
<tr>
<td>Columbia River at Grand Coulee</td>
<td>28,000,000</td>
</tr>
<tr>
<td><strong>Boise District</strong></td>
<td></td>
</tr>
<tr>
<td>Snake River at Moran</td>
<td>470,000</td>
</tr>
<tr>
<td>Snake River near Shelley</td>
<td>1,020,000</td>
</tr>
<tr>
<td>Snake River at King Hill</td>
<td>1,250,000</td>
</tr>
<tr>
<td>Boise River near Twin Springs</td>
<td>246,000</td>
</tr>
<tr>
<td>Boise River at Motus (Subject to regulation)</td>
<td>52,000</td>
</tr>
<tr>
<td>Payette River near Emmett</td>
<td>930,000</td>
</tr>
<tr>
<td>Snake River at Oxbow</td>
<td>2,400,000</td>
</tr>
<tr>
<td>Salmon River at Salmon</td>
<td>480,000</td>
</tr>
<tr>
<td>Salmon River at White Bird</td>
<td>3,500,000</td>
</tr>
<tr>
<td>Clearwater River at Spalding</td>
<td>4,600,000</td>
</tr>
<tr>
<td>Snake River near Clarkston</td>
<td>11,800,000</td>
</tr>
<tr>
<td><strong>Portland District</strong></td>
<td></td>
</tr>
<tr>
<td>Columbia River at Trinidad</td>
<td>30,000,000</td>
</tr>
<tr>
<td>Columbia River at The Dalles</td>
<td>41,500,000</td>
</tr>
</tbody>
</table>

**Expected Crest Flows and Stages**

<table>
<thead>
<tr>
<th>Flow (Cubic Ft. per second)</th>
<th>Feet</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Columbia River</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trinidad (unregulated)</td>
<td>230,000</td>
<td>39.5</td>
</tr>
<tr>
<td>Trinidad (regulated)</td>
<td>200,000</td>
<td>37.5</td>
</tr>
<tr>
<td>Umatilla (unregulated)</td>
<td>310,000</td>
<td>13.6</td>
</tr>
<tr>
<td>Umatilla (regulated)</td>
<td>280,000</td>
<td>12.5</td>
</tr>
<tr>
<td>Celilo Falls (unregulated)</td>
<td>315,000</td>
<td>17.0</td>
</tr>
<tr>
<td>Celilo Falls (regulated)</td>
<td>285,000</td>
<td>16.0</td>
</tr>
<tr>
<td>Vancouver</td>
<td>.......</td>
<td>11.0</td>
</tr>
</tbody>
</table>

**Willamette River**

| Portland | 11.0 | June 2-8 |

Due to anticipated storage in the Columbia reservoir in May and June, 2,000,000 acre feet have been subtracted from the predicted seasonal flow at Grand Coulee, Trinidad, and The Dalles.
Mr. Elmer Fisher will now carry on with his paper, followed by Mr. Linsley who will summarize the Weather Bureau presentations and discuss the methods of crest flow computation.

Fisher: It will be recalled that a table was appended to my remarks on page 26 of the proceedings of the Columbia River Basin Interstate Water Forecast Committee meeting in 1943, giving crest stages of summer floods from 1921 to 1942. For the information of anyone who wishes to continue that table the following note may be added to the aforementioned table.

In 1943 the crest at Portland was 19.8 feet, June 24th. The Willamette in the Portland Harbor was above flood stage, 18 feet, from June 2 to 7 and from June 21 to July 7, a total of 22 days. The average stage for June 1943 was 16.4 feet.

There were four distinct crests noted at Celilo during last year's flood, -- now these may not exactly agree with the U. S. Geological Survey determinations because they may have corrections that I do not have, but they will be substantially the same, -- April 23, 442,000 c.f.s.; June 3, 4, 523,000 c.f.s.; June 13, 488,000 c.f.s.; and June 21, 546,000 c.f.s. After the April crest, the discharge at Celilo receded to about 278,000 c.f.s. on May 21.

Now, I am submitting this for what it is worth: April temperatures in Idaho averaged 3.7° above normal and May and June temperatures averaged 2.8° and 3.8° below normal, respectively. Precipitation averaged 9 percent above normal for April and 86 percent of normal for May and 1.57 percent of normal for June. About the same temperature and precipitation conditions occurred in Western Montana as those indicated above for Idaho.

According to Mr. Marr's 1944 Snow Survey report and U.S.G.S. records for 1938, there were 10,070,000 more acre feet of water discharged at Celilo for the 6 months April 1 to September, 1943, (inclusive), than for the same 6 months in 1938. The crest discharge at Celilo, May 31, 1938, was 609,000 c.f.s. stage 24.7 feet. The 1943 April-September, inclusive, Celilo discharge was 751,000 acre feet more than in 1933 when the stage in the Portland Harbor was 24.8 feet and the maximum discharge at Celilo was 722,000 c.f.s. You will note from the above facts that the exact prediction of a crest stage is most difficult and depends to a large extent on the evaluation or prediction of things to come as well as a correct appraisal of data already available. It is believed that the prediction of the seasonal discharge isn't so difficult when the major portion of the seasonal precipitation and monthly distribution are known, although there are many factors to be considered and correctly interpreted.

For several years it has been my privilege to participate in this meeting to the extent of submitting a large portion of the data assembled by the Weather Bureau. My activity this year is to coordinate the flow in the Snake below Lewiston with discharge at the Grand Coulee Dam and the other rivers in the middle and lower Columbia Drainage and to forecast a probable crest stage for important stations in the Middle Columbia region and in the Columbia at Vancouver and the Willamette at Portland.
The most important tributaries in the Middle Columbia below Grand Coulee, in addition to the Snake, are the Okanogan, Methow, Chelan, Yakima, John Day, and Deschutes Rivers. The most important river tributary with which we are concerned in the Lower Columbia at this time is the Willamette River system. The Willamette may be a very important factor in determining the crest stage in the Portland and Vancouver harbors.

From 1933 to 1943, inclusive, the average discharge at crest stage at Celilo has been about 477,000 c.f.s. The Columbia at Trinidad has contributed on the average about 67.2 percent of this amount and the Snake below Lewiston (as determined from records at Riparia and Clarkston) has contributed an average of about 26.5 percent of the amount, leaving only 6.3 percent of the flow at crest stage at Celilo to all other rivers entering the Columbia below Trinidad and the Snake below Clarkston, Washington.

From the remarks of Mr. Veatch, it appears that stage of the reservoir at Grand Coulee Dam would be about 1262 above MSL on May 1. Is that right, Mr. Veatch?

Veatch: It was 1262 today.

Fisher: At any rate there is going to be some withholding by Coulee but, as Mr. Veatch has pointed out, the Columbia probably will be an unregulated stream at crest stage, although he also stated that there is some possibility that it might be slightly regulated at crest. Is that right, Mr. Veatch?

Veatch: Yes.

Fisher: With that proviso, during the 21 days following May 1 it will be raised to the elevation 1290 feet MSL. This will mean a withholding of approximately 50,000 cubic feet per second daily.

Barring any unusually high temperatures of several days duration or precipitation materially above normal over areas of the Upper Columbia contributing major portion of the run-off, it is predicted that a crest of about 315,000 c.f.s., stage 17.0 feet unregulated; or 285,000 c.f.s., stage 16.0 regulated, will occur at Celilo; and 310,000 c.f.s., stage 13.6 unregulated; 280,000 c.f.s., stage 12.5 feet regulated, one day earlier at Umatilla. The crest stage at Celilo is expected to occur the first week of June. With the normal river flow at the above predicted crests being allowed to pass Bonneville and barring a freshet in the Willamette and other streams with sources in the Cascades, the stage in the Portland and Vancouver harbors are not expected to exceed 11 feet.

One very important point that should be stressed in connection with this forecast is that barring unforeseen extremely high temperatures and heavy precipitation during the next two months, farmers can safely make the fullest use of the low lying agricultural lands in the Lower Columbia and Willamette Basins.

Following is a table showing the discharge contribution of principal streams in the Middle Columbia to the crest discharge at Celilo. It will be noted that for the most part the crest
stages in the large tributaries are not coordinated with each other. In other words, the crest stages at Lewiston occur at a different time than the crest stages at Trinidad, so usually the crest is not coordinated. In this Table I have included all those other tributaries that I mentioned above and their contribution roughly timed to show the portion which they contributed to the crest at Trinidad or at Celilo.

Crest at Celilo, Oregon on Columbia and Snake and
Other Important River Data Middle Columbia and Snake Rivers
Below Coulee Dam and Lewiston, Idaho, respectively

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Crest Stage</th>
<th>Crest Disch.</th>
<th>Celilo Stage</th>
<th>Celilo CFS</th>
<th>Celilo Crest</th>
<th>Celilo CFS</th>
<th>Crest Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1933</td>
<td>June 23-24</td>
<td>18.6</td>
<td>376000</td>
<td>14000</td>
<td>113000</td>
<td>700</td>
<td>255000</td>
<td>42.7</td>
</tr>
<tr>
<td>1934</td>
<td>May 31</td>
<td>24.7</td>
<td>609000</td>
<td>14700</td>
<td>204000</td>
<td>7390</td>
<td>309000</td>
<td>48.7</td>
</tr>
<tr>
<td>1935</td>
<td>May 21</td>
<td>18.9</td>
<td>387000</td>
<td>4500</td>
<td>104000</td>
<td>757</td>
<td>259000</td>
<td>42.8</td>
</tr>
<tr>
<td>1936</td>
<td>June 11</td>
<td>15.8</td>
<td>275000</td>
<td>1680</td>
<td>7500</td>
<td>7310</td>
<td>360000</td>
<td>48.7</td>
</tr>
<tr>
<td>1937</td>
<td>June 18</td>
<td>20.1</td>
<td>431000</td>
<td>1680</td>
<td>9450</td>
<td>3200</td>
<td>300000</td>
<td>50.2</td>
</tr>
<tr>
<td>1938</td>
<td>June 21</td>
<td>23.2</td>
<td>549000</td>
<td>9640</td>
<td>309000</td>
<td>5210</td>
<td>309000</td>
<td>45.2</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>477000</td>
<td>9196</td>
<td>4831</td>
<td>291700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Crest Stage</th>
<th>Crest Disch.</th>
<th>Celilo Stage</th>
<th>Celilo CFS</th>
<th>Celilo Crest</th>
<th>Celilo CFS</th>
<th>Crest Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1934</td>
<td>June 22</td>
<td>20.3</td>
<td>209000</td>
<td>42000</td>
<td>320000</td>
<td>5290</td>
<td>320000</td>
<td>45.2</td>
</tr>
</tbody>
</table>

NOTES: Except in 1936 the discharge at Coulee was increasing during the two days following the discharge given above.

The discharges of the Okanogan and Chelan Rivers enter the Columbia above Trinidad and therefore constitute a portion of the discharge.
Canfield: Mr. Fisher, you forecast the peak discharge at Celilo unregulated as 315,000 second feet?

Fisher: 315,000.

Canfield: And then you gave a figure regulated?

Fisher: 285,000.

Canfield: I thought you had previously stated that you expected a little regulation from Coulee reservoir at the time of peak.

Fisher: Mr. Veatch has just informed us that there wouldn't be very much effective regulation on this year's peak at Coulee.

Canfield: Have you any forecast of the run-off in acre feet for the 6-months' period April to September?

Fisher: I have no other forecast except that submitted by Mr. Codd. We worked those out together.

Canfield: Mr. Work, I believe we are approaching the time we should adjourn for lunch. I will turn the meeting back to you.

Work: We are going to lunch in the Georgian Room, Old Heathman Hotel. Mr. Harper, who, with Mr. Burtner, is covering the meeting for the A.F. and local papers wants a picture. If you gentlemen will remain a minute, they will set up their camera.

Some of you came in late, and we should like you to fill out these registry cards.

For those of you who can't come over to the luncheon, we will reconvene here at 1:30.

(Thereupon, at 12:05 o'clock p.m., a recess was taken until 1:30 o'clock p.m. of this day, Tuesday, April 18, 1944, at which time the following further proceedings were had herein:)

Work: When we adjourned we were full-handed, and now we are short two or three subchairmen. If we adjourn again, I am afraid we won't have any chairmen left and a very small group, so we will pick up the thread of discussion with Mr. Linsley's comments.

Canfield: Yes. Mr. Linsley, also of the Weather Bureau, is next on the program. Mr. Linsley is from the Sacramento office, Hydrology Section.

Linsley: I will keep my remarks as brief as possible and just say that we predicted this run-off volume at The Dalles and differ with Mr. Marr. We estimated -- our figure, of course, is for April-July -- 41,500,000 acre feet at The Dalles, and then we further made a correction for April-September, and we have a figure of 58,000,000 acre feet. In general, we run about 10 percent less than Mr. Marr, except, I think, in a couple of the Snake River tributaries we were just slightly higher, but in very close agreement.
A Member: Pardon me. Did you say that figure, 58,000,000, was for April-July?

Linsley: April-September.

Work: Excuse me, Mr. Linsley. That would be about 15 percent difference in estimate, would it not -- 58,000,000 as against 66,000,000?

Linsley: That is a little higher than the 10 percent, yes. That 10 percent figure is sort of an over-all average for the whole basin.

The principal point I wanted to discuss now is with regard to the peak flow as set at Celilo Falls. Our forecast, which is 315,000 second feet, assuming no effect of regulation at Grand Coulee, was developed as two independent forecasts. Mr. Fisher made one by the usual method, and Mr. Codd and I spent the last four or five days deriving one by the statistical methods which he discussed this morning.

The major element in predicting the peak seems to be the total volume of flow, as you would naturally expect, with corrections for the relative contribution of the Snake in the Upper Columbia and also a correction for the flow during the first week in April. The high flow there, both extremely high and extremely low flows in April, tend to reduce the peak and about normal flows give us the full peak realization. One point which was very interesting was that in the 30 years of record which we analyzed, in only 2 years was there shown appreciable effect of abnormal spring and summer weather on the resulting peak at Celilo Falls. Those years, I believe, were 1928 and 1933. It might also be interesting to mention -- and I don't know whether you will believe this or not -- that we had developed a preliminary set of relations last summer about the first of June, and a forecast by that set of curves showed 546,000 for Celilo, so Ashton wrote it down in his book.

Canfield: What was the name of that bird Mr. Phillips mentioned that looked backward? (Laughter)

Linsley: We are sorry that we didn't get started on that in time last year to be at the meeting.

We also developed relations for the time of peak at Celilo based on the same factors. That, of course, shows much more variation than the amount of peak, but it is reasonably consistent. I think there is a probable error of seven days in the relation, that is, a 50-50 chance of having an error of greater than seven days. And those curves indicated a peak on June 7.

Canfield: June 7th this year?

Linsley: That is right.

Canfield: Thank you, Mr. Linsley, for this summation for the Weather Bureau. Well, I see Henry Stevens is arriving just at the opportune moment. He must be a good forecaster. He came in just as I was
about to pass his name and go on to Mr. Wahlo. Knowing Mr. Stevens’ interest in power, I am wondering if we shouldn’t consider the probable minimum flow this summer of the Columbia River at Bonneville — when a discharge may be reached only sufficient to care for requirements of the fish ladders of about 3,500 second feet, and the capacity of the units, or a flow of about 80,000 second feet? I submit that for consideration by this group in following years. Mr. Stevens, I will call on you at this time for a statement for the Bonneville Power Administration, to be followed later by Mr. Wahlo’s forecasts.

Stevens:  
Mr. Chairman, I haven’t any prepared statement, however, I have been considering the statements made this morning as they relate to power development. The information which has been presented as to the probable stream flows for the next 4 to 6 months, is valuable to us in the power field in order that we know when we should hold back and use power resources other than reservoirs and let the reservoirs fill up. Our critical time as to power on the Columbia River, of course, occurs in the wintertime, when it becomes necessary to draw on the reservoirs which we have had the foresight to fill for that purpose. With the present installations at Coulee and Bonneville, we anticipate we will start drawing on Columbia River reservoir in minimum years sometime about the middle of October, and that will continue until probably the latter part of March. Withdrawal ceased this year on about the 6th of April. Last year we withdrew water from storage which did not go through the machines at Coulee, because of the limited installation there. That withdrawal was needed to supplement stream flow at Bonneville in order to generate the amount of power necessary to carry the loads. A considerable amount of this power was used by the other utilities in order to conserve strategic oil supply and to conserve reservoir storage.

These snow surveys will become even more valuable in the future, and I think that they can be properly extended to a greater purpose. It is encouraging, indeed, to see the work that has been started on the West Coast. That is information we have never had before and is going to be valuable with our interconnected systems.

Canfield:  
Mr. Stevens, what is the requirement in discharge of the Columbia River to take care of fish ladders and the power generation of all the wheels at Bonneville?

Stevens:  
Well, that has been estimated at about 2,500 second feet low stream flow, and including the leakage, it is about 3,500 second feet at high water.

Canfield:  
I mean the total requirements of the fish ladders and the power generating equipment.

Stevens:  
You mean for full capacity at Bonneville?

Canfield:  
Yes.

Stevens:  
About 110,000 second feet, 110,000 to 120,000; depending on the head.
Eddington: About 127,000 the other day. We had a flow we figured was full capacity.

Canfield: Well, that wouldn't be a 24-hour demand, would it? That would be your peak load?

Stevens: That means the machines can use that much water if we have it available. Under the present operations, of course, that amount of water is only used for carrying the peaks when we have the full capacity of the plant. It is very improbable at any time that the Bonneville Plant would be operated at that full capacity for 24 hours a day, day after day.

Canfield: Wasn't there a time last year at end of September when, for the first time, no water was going over the spillway, when the flow was about 80,000 second feet, and ----

Stevens: I haven't the data on that. Does anybody?

Canfield: Well, I think it was sometime in September they were able to utilize all the flow.

Stevens: I think it was from the first of October to December, or after that, yes, up until February. I don't believe that we are spilling very much water at Bonneville.

Canfield: At Celilo the lowest daily mean discharge in September and October was 81,100 second feet on October 1; during the past winter, 62,800 second feet on February 21, 22.

LoFever: There have been additional machines added.

Stevens: Yes. The additional unit came in at Coulee, I believe, in November.

Christensen: Yes.

Stevens: In November. And our last machine in ----

Christensen: February.

Canfield: Last year Mr. Wahle gave us a forecast of peak discharge and the run-off by statistical methods. He is here again today, so I will call upon him now to present this subject.

Wahle: Last year marked my first attendance at these meetings. I am certainly glad to be here again this year.

I was afforded the opportunity last year of introducing an entirely different concept for forecasting stream flow -- that is, peaks and total annual flow. For the benefit of those who didn't hear that little talk last year, I might say that this method is known as Pattern Analysis and employs the first 6 months' flow of a run-off year as a measure or a key to the last 6 months' flow, to peak flow and annual run-off. I might add that this method does not take into consideration any other factors whatsoever as to temperature or snowfall, nor anything
except a consideration of the hydrograph in evidence for that first 6 months' flow. The forecast derived from those considerations, the pattern analysis, is made on April 1st of each year. Behind us we have one year of application, in a sense, two years, because the preliminary paper was offered early in 1942, and the forecast offered at that time enjoyed a gratifying degree of success. Last year, as Mr. Phillips stated, the forecast indicated 155,000,000 acre feet as total annual run-off for the year -- that is, from October 1 to September 30. It turned out to be 155,335,000 as calculated for Bonneville and corrected for Coulee storage. That is very close, within a fraction of one percent, but as to my peak forecast, Mr. Phillips kindly omitted mentioning that, but I will. We forecast 685,000 second feet at Bonneville, and the actual peak turned out to be 549,000 second feet. Last year was remarkable in some respects in that we had a very high flow in April of around 450,000 second feet. That was followed by a cold spell that caused a sharp drop in river flow of around 150,000 c.f.s.; and if I recall correctly, that is the greatest drop for that time of year in the history of the river -- that is, for the period of record. In that connection, it was observed that last year's pattern of flow finds no similarity in the various years of record. We picked out several years, as shown to the assembled group last year, that exhibited a pattern very similar to the first 6-month flow of last year, but the following 6-month flow pattern found no duplication in the period of record. It is likely, of course, that such pattern departures have been witnessed many times in the past, but we have no record of them if they have occurred. We can expect many such pattern divergences in the future. One thing that I wish to mention in this connection is that a study of temperature and of snowfall in relation to patterns selected according to the theory of pattern analysis, if combined with the pattern behavior considerations, would go, I believe, a long way towards eliminating the possibility of any extreme error through pattern departures.

Now, low flows during that critical first 6-month period can be caused by drought and cold or by either of those, and consideration of temperature and snowfall would eliminate from the pattern selections those years that were not similar in the elements of temperature and snowfall. This last year I haven't possessed the time to go into those factors of temperature and of snowfall as I certainly would have liked to have done, but what I have found indicates that there is much promise in that line of inquiry.

Of immediate importance and interest, however, is this period at hand right now. We are faced by a run-off year that really doesn't offer much by way of promising any excess run-off, and that has, I think, been very thoroughly stressed by other gentlemen before me today. I believe that lack of excess flow is promised because analysis has brought out certain facts, as follows:

The Columbia River run-off at Bonneville for the first 6 months of the current run-off year has averaged 80,880 c.f.s., as
corrected for Coulee storage. In itself, this is strong testimony of a low run-off, low-peak year. Only five years of record have fallen below 80,000 c.f.s. average for the first 6 months, and only one of these exceeded 500,000 c.f.s. peak, or 100,000,000 acre feet run-off, for the entire year, from October 1 through September 30. There were found to be six years in the record exhibiting flows of a pattern with this year. These years, analyzed according to the first phase of pattern analysis, indicate 111,000,000 acre feet and 409,000 c.f.s. peak; and the second phase of pattern analysis, that concerning yearly pattern similarity, shows that two fair one-year patterns exist. Here, again, we found an indication of low run-off and low peak. The record does not supply any worthwhile period patterns of greater length than one year, but it enables us to utilize only the first two phases of pattern analysis, and these give us the following forecast for the run-off year 1943-44 at Bonneville: a peak of 397,000 c.f.s. and a total run-off of 110,000,000 acre feet.

Canfield: Thank you, Mr. Wahle.

Peterson: Mr. Wahle, you have analyzed these patterns, and, as I understand it, there are two criteria that you study. First, there is the volume of water that has flowed down during this 6 months, and the other is the manner in which that flow occurred. Is that right?

Wahle: Yes, the patterns include the time, the magnitude and the character of flow.

Peterson: And the area underneath that shape determines the volume of water. Do you use the volume of water that has flowed for that first 6 months as a criterion of the total volume to be expected in the next 6 months, and do you use the shape to determine the peak? I think you have explained it, but it wasn't quite clear to me that the shape is an indication of the expected peak and the volume is an indication of the future volume.

Wahle: Well, I don't know as I get your question exactly, Mr. Peterson, but I may say this: the volume of flow evidenced in the first 6 months apparently has a very great bearing on what will come thereafter. Now, the exact reasons for that occurrence I haven't had occasion to determine, but it seems that if that first 6-month flow is, in fact, a key to that last 6-month flow as to both pattern and volume, it must arise from low level run-off -- that is, valley, and the small streams and rivers that reflect water and early spring rainfall and the low level snow melt. Now, it would indicate, then, that the run-off during that critical 6-month period, which I use as a starting point, would have a direct bearing on the high level snowfall and the subsequent melt; so that the first 6-month flow of big volume ordinarily -- and I might say almost invariably -- indicates a big run-off, and according to the way in which that run-off occurs during that first six months -- that is, the pattern that it makes -- I am enabled
to go back into the record and pick out similar years, like a similar type of run-off, that gives me, in turn, a key as to what I might expect as to peak. Does that answer your question?

Peterson: Well, Mr. Wahle, what I am driving at is this: If the volume of water that has flowed during the first 6 months is a criterion of the volume of water to be expected during the next 6 months, does it matter what pattern it is?

Wahle: Well, it matters what pattern it is insofar as the estimate of the peak is concerned.

Peterson: No, I am talking about the volume of water.

Wahle: Well, apparently -- the selection last year of patterns of a nature to the first 6-months' flow was very good, because the estimate turned out to be very correct.

Peterson: On the volume, or on the peak?

Wahle: On the volume.

Peterson: How did it turn out on the peak?

Wahle: An 18 percent error on the peak. Now, if we take the excess April flow and add it to the June-July flow, why we have a peak of the order of 685,000. It didn't occur that way. A pattern analysis permits a forecast. I can't go back and change that forecast because of some further consideration and have the method involved amount to anything. I have got to make a forecast and stand on it. If it is worthwhile, well and good. If it isn't, well and good, too. Just as if an economist advises a business man. If the man loses money, he can't very well go back and help it much. So it is with the stream flow.

Peterson: In other words, a new pattern was established last year?

Wahle: That is right.

Peterson: And a new pattern may be established any year in the future.

Wahle: That is true.

Peterson: You are open to that hazard.

Wahle: Continually. We can expect times, I think, when there is a possibility of error, and that is the reason I suggested the study of temperature and snowfall in relation to pattern analysis, to eliminate any chance of extreme error. That would be a very logical thing to do.

Peterson: Thank you very much.

Canfield: Mr. Wahle, your estimate for the year is 110,000,000 acre feet. To bring it on a comparable basis with some of the other estimates made for the 6-month period ending September 30, it would be necessary to deduct the run-off to date for the first 6 months, which is about ---
Wahle: 29,000,000

Canfield: ...28,000,000 acre feet.

Wahle: They gave it at the office the other day, and, as I recall, the figure stands between 29,000,000 and 30,000,000 acre feet.

Canfield: I was correcting that to the natural flow for the amount released from Coulee storage.

Wahle: That is correct.

Canfield: I think that is right. We will subtract 30,000,000 acre feet. Eighty million acre feet, then, would be your estimate of run-off for the latter 6 months of the current water year?

Wahle: That is true. Now, that is at Bonneville, and I understand there is about 4,600,000 acre feet on an average that comes in below the Celilo gage.

Canfield: Yes. A year ago, I think, that inflow for the entire year was about 5,000,000 acre feet. Suppose we reduce that 80,000,000 by 2,000,000, which would give, then, about 78,000,000 for The Dalles, which would compare with these other values of 58,000,000 by the Weather Bureau, and 66,000,000 by Mr. Marr of the Soil Conservation Service. If you don't mind, then, I would put that figure down as yours: 78,000,000 for the 6-month period.

Wahle: Yes. That is for the 6-month period from April 1 to September 30.

Canfield: Another Agency interested in the peak Columbia discharge is represented here today. This is the Agency operating the power units at Bonneville Dam. That is the Portland District of the Army Engineers. Mr. Pederson has represented that Agency in the past, but he also is ill, and is not able to be here, so Captain Drager will present information for the Army Engineers.

Captain Drager, this, I believe, is the first time you have met with us. We are very glad to have you here and receive your contribution.

Drager: Our forecast of total run-off for the 6-month period, April 1 to September 30, checks that which Mr. Marr has developed, namely, 66,000,000 acre feet. On some of the tributary streams, we did not check Mr. Marr, but after all, we are interested in the total, so our forecast is also 66,000,000 acre feet of run-off.

We have estimated the peak flow at 340,000 c.f.s. at The Dalles. This estimate includes no allowance for regulation at Grand Coulee. A rough estimate on regulation at Grand Coulee reduces this peak flow to 290,000 c.f.s. It has been stated here today that no regulation of peak flow is anticipated at Grand Coulee, therefore, our forecasts would be 340,000 c.f.s. peak flow and 66,000,000 acre feet run-off.

Canfield: Thank you, Captain Drager. I had on the program Mr. Allison, Meteorologist of the U. S. Army Engineers. I don't see him here.
now, but I think he told me that he wasn't sure that he could be back this afternoon.

Well, we have reached the end of the scheduled program for this section. We will entertain discussion from anyone at this time. Anybody else care to make a prediction or forecast telling us of things to come? (Pause) Well, Mr. Work, I will turn the meeting back to you. As far as peak discharges of the Columbia River are concerned, we have three estimates: 315,000 by the Weather Bureau; then 397,000 by Mr. Wahle; and 340,000 by Captain Drager of the Army Engineers; all in terms of second feet. For run-off, we have: Mr. Marr, 66,000,000; Mr. Codd, 58,000,000; Mr. Wahle, 78,000,000; and the Army Engineers, 66,000,000; all in terms of acre feet.

Linsley: In that run-off volume, our 58,000,000 assumes 2,000,000 will be stored at Coulee. If the other forecasts are for natural flow, ours should be 60,000,000. 58,000,000 is what we expect to pass.

Canfield: You expect that will be the observed run-off?

Linsley: That is right.

Work: Well, all right, Mr. Canfield. We are getting some valuable data into the record. I have no comments to offer on these various estimates. We will pass on to the section designated "Effects of Short 1944 Water Supply on Pacific Northwest Power Planning and Coordination."

We are fortunate to have with us today Mr. E. N. Peterson, Coordinator of the Pacific Northwest Interconnected Systems. That is an interconnection of some eleven utilities, both privately and otherwise owned. Mr. Peterson has returned recently from a meeting of his group, held, I believe, in Boise, and he may be able to give us a resume of some of their plans for meeting this emergency.

Peterson: I am sorry I don't have any program prepared, but I have a few comments that might be of interest to this group. Mr. Andrews this morning made the remark that this organization is a fully cooperative group, and it is a fully cooperative group. I have had the good fortune to be associated for the past three years with another -- I would call it a fully cooperative group, namely, the Northwest Power Pool. As you know, it includes Idaho, Utah, Montana, Washington, and most of Oregon; and in it are a Federally owned power system, municipally owned power systems, and privately owned power systems, all working together.

The review of the Boise meeting would be rather boring to you if I did anything but mention a few of the subjects that we discussed. They have a great deal to do with water supply, because water supply is a very important element to us, as you would surmise, so I will merely mention that we discussed at Boise the water supply as we saw it at that time. Those opinions on water supply are rather obsolete, in view of what has taken place here today, and I think should be superseded by the opinions that we will draw from the results of the surveys made at this meeting.
However, we discussed another item of great importance. It is intimately connected with the water supply, although it doesn't seem so on the surface, namely, the principles of interchange of power. Those principles of interchange have been established over a period of years, and every once in a while we will run into a difficulty due to something that has been overlooked. So once in a while, usually once a year, we review our principles of interchange and try to bring them up to date. Usually those reviews involve considerable debate, some of it fairly heated, but it ends in progress, without exception.

Another subject that we discussed is operating programs. We draw up 2-year operating programs. We have to guess the water for 2 years. That is more difficult than what you gentlemen usually do. The first year we think we ought to guess it pretty closely, and the second year, it is "deuces wild."

The operating program is merely a schedule of operation by each system of its respective power plants. It is worked out in extreme detail and is an awful headache to the poor fellows that have to work it out, I can assure you, particularly as they have to obtain the agreement and the approval of the members who have to live with that operating program. However, we have been around the circle, now, three years -- I mean we have been around this job for three years, and we have gotten somewhat acquainted with the problem and with the men we work with, and things are going along fairly well.

A third item we discussed is the operation of reservoirs. That is a very important subject to the Power Pool, because the reservoir storage represents the electric energy that we have in the bank, so to speak, and we draw on it at such times and to the extent that the natural flow gives us less than we require for carrying the load, and we must husband the energy we have in the reservoirs so that we won't run short at the end of the season and yet won't waste too much. We have to waste a little, but we try to reduce that waste to a minimum.

Another very important subject is the subject of bottlenecks. Those are not glass bottlenecks, by the way; they are some other kind. (Laughter) We find that we have restrictions in transmission capacity between the various systems, and those restrictions sometimes result in things that we don't like -- for example, the burning of critical fuel in one area, and the wasting of hydro in another area, and the impossibility of getting the power from the region of surplus into the region where critical fuel has to be burned. Those are very serious bottlenecks in the operation of the Pool and are gradually being eliminated through the development and building of more transformers and transmission lines to get the power through.

Now, I said the Pool is very much interested in this forecast of water. There are approximately three and a half million kilowatts of capacity in this Northwest Power area. Of that, almost 3,000,000, or 85 percent, represent hydro power; the rest, thermal power, mostly steam, a few oil burning diesel plants. It is
natural, then, that we, too, are vitally concerned with how much water we are to get in the coming season. Snow surveys give us a clue to that. The high snows and the early snows that pack down give us a sustained flow in the latter part of the summer when the natural supply would otherwise be way down. On the other hand, the lower snows and those that fall later in the season melt quickly, as you know, and, while they will help to fill our reservoirs, don't do us much good for natural flow in the later part of the year.

I was somewhat disappointed that we didn't have, as I had hoped, a more complete discussion on ground water. That is a very important element for power, because the ground water is really the biggest reservoir of all, from which we draw when there isn't sufficient rainfall. Of course, we don't have much control over our draft from the ground water, but, nevertheless, we count on it when it is there, and when it is not there we worry about the fact that it isn't. For example, in Montana last year there wasn't a great deal of rainfall. There wasn't a great deal of snow melting. But yet Montana had an excellent water power year. It was lush. Most of the regions other than Montana were fairly tightly squeezed, but Montana had plenty of power and was able to help out the others to a considerable degree. That was due in a large measure to the high ground water level; springs that frequently run dry were going full blast last year, and furnished very valuable run-off to the streams, which was converted into power.

We of the Pool are taking steps to go into this matter of ground water considerably more thoroughly than in the past, because we think that it is to us almost as important as the snow surveys. The Washington Water Power Company has done a great deal on that and Montana has done a little, and possibly there have been more surveys made of wells to determine the ground water. I am not referring, now, to the surveys made by the Government. I am talking about surveys made by other industries. Possibly there has been some work done that I don't know about. But we are planning to organize that for our benefit, for the benefit of the Pool, and get some information as to ground water regularly for the purpose of planning our operations.

Now, in order to tie in the water forecasts with the operation of the Power Pool, I will just indicate briefly what we do. We set up this operating program based on the critical water year -- Mr. Canfield said we should look not only for what was probably likely to happen, or what has happened in the past, or what the average is, but what is the critical, what is the lowest water supply that we can expect to have in the region. Well, the coordinating group members are very pessimistic. They expect a critical year every year. They hope they won't get it. As I told Mr. Work, we expect the worst and hope for the best. We expect the worst every year. In other words, we have to plan operations and the drafting of the reservoirs in such a manner that if we get critical water -- in other words, the poorest water
supply that has ever occurred before, (and we assume we will never get a worse year than that), we shall have enough water in our reservoirs and enough fuel for our steam plants to carry our load to the end of the dry season. That is our principal criterion. To do that, of course, we have to burn some fuel, and we operate the cheaper plants first, or those where fuels are plentiful, in preference to those where fuel is less expensive and more critical. In connection with that, of course, we have to schedule the operation of the reservoirs. All the reservoirs in the region are drafted in accordance with this schedule, based on critical water conditions. Dates are set down, and elevations, below which the reservoirs should not be drawn. If they are drawn below that elevation on that date, there is danger of not being able to carry the load from then on. That would be the case if critical water should occur from then on, so these "Rule Curves," as we call these schedules of reservoir operation, are very important, and in fact are critical in the operation of the Power Pool.

Now, how near we come to critical water, of course, is a matter of guesswork, but we get a great deal of help from this group. Your surveys of the snow and your prognostications of the future water supply, while you think more of irrigation and agriculture, nevertheless help us because those same water supplies affect our power supply in the future. Another way in which you help us a great deal is that we have to estimate the oil that should be purchased, particularly now when the War Production Board is on our neck to economize on oil. We must tell them in advance how much oil we are likely to require in the Pool, and we make estimates of that oil based on the water supply. We give them the estimate based on critical water supply, which is presumably the maximum amount of oil we shall need, and then we give them another figure which isn't quite so tough, based on a more probable water supply.

It looks from the results of this meeting so far as if there is a dry period ahead, very dry. Possibly we have a critical year ahead of us. However, we are planning on a critical year. That is our basis for the operating program. If we follow our program carefully, there is no question but what even under critical water conditions the load that we expect to arrive in the Northwest in the coming year or two can be carried.

Now, there are present here a few of the engineers who attend the Operating Committee meetings, and it might be that some of them would like to say something in connection with the operation of the Pool or anent the Pool. Mr. Henry Stevens, you gave a talk that affected the Pool in some ways. I wonder if you wish to add anything on the subject of Pool operation.

I think that we will have a critical period for hydro, beginning next December until March. In view of the snow shortage on the mountains and probable reduced run-off, it looks to me as if we will have to use practically all of our reservoired supply by the first of next year.
Peterson: We are afraid that the critical situation will come sometime earlier, Henry; even in July.

Mr. Christensen, do you care to say anything about the Pool?

Christensen: I don't know that I have much to add, Mr. Peterson. During Mr. Canfield's administration some reference was made to the use of the Columbia River reservoir for flood control. As I understand it, no attempt is being made to use that reservoir for flood control this year. The reservoir will be allowed to fill as the inflow increases until the reservoir is filled, without regard to when the peak flood might occur. As Mr. Veatch pointed out, use of the reservoir might be made later on, particularly in periods when high run-off is expected, for flood control. But I wanted to correct any impression that it is intended to use the reservoir for flood control this year.

Peterson: Mr. LeFever?

LeFever: I think you have covered the topic very well. There is one question I should like to ask: How many wells are there that have already been read, or studied, throughout this district? In the East I know the Governmental bodies there have a large number of wells that are read and reported, but I haven't seen anything much in regard to the West, especially on the Pacific Coast, and I am just wondering how many wells are being read throughout this territory, if any?

Canfield: I might make a brief statement, although I am in the unfortunate position of speaking for another Division of the Survey. I am with the Surface Water Division and Mr. Piper, with the Ground Water Division, has an office in Portland. He was on the program but was unable to attend today. He is in charge of the investigations of ground water supplies in the Western states: Washington, Oregon, California, and parts of Idaho. I know he has certain key wells where observations of ground water levels are taken periodically, has several in the Spokane area, several more in the vicinity of Tacoma, particularly in connection with the water supply of the City of Tacoma; a very comprehensive investigation has been made and is being continued in the Spokane River Valley. Throughout the Northwest a few key wells are maintained and observations made regularly. I am not in a position to give the results of those observations. I don't have the information. Possibly that might be supplied for the record later on by Mr. Piper.

Piper: As of 1942-43, the Geological Survey was making periodic measurements of water level in 160 observation wells in Washington, about 55 wells in Oregon, and 3 wells in northern Idaho. About 40 percent of these are basic observation wells, at which water-level measurements will be continued as long as is feasible; frequency of measurement ranges from weekly to twice yearly. As of April 1944, water levels in key wells were somewhat above average in northern Idaho, about average in eastern Oregon, but somewhat below average over nearly all of Washington and in western Oregon.
Peterson: Mr. Ellis, do you have any comments you wish to make?

Ellis: No. I might ask another question: I have noticed from our records, particularly of the Lewis River stream flow, that, as a rule, we have about a fixed number of dry months a year, and it doesn't matter whether those months start early or late. We usually have 5 low months on Lewis River at Ariel. I was wondering if anyone else has noted a fairly constant number of low months annually for any other streams and whether that is a fairly reliable condition on which to base forecasts. Now, it looks as if our low water will start this year at least a month earlier than normal, as it did in 1941, and if we follow 1941, we also will have an earlier raise in the fall, so that we wouldn't be hit nearly so hard, because we are dependent largely, in the early fall at least, on rainfall. If we get an early fall of rain, then we will have considerable increase in natural flow.

Peterson: You are speaking for the Northwestern Electric Company?

Ellis: Yes.

Peterson: Thank you, Mr. Ellis.

Under this section is listed Mr. Vic Johnson, of the Portland General Electric Company, to talk on the Clackamas River. We will be very glad to hear Mr. Johnson's words if he is here.

Canfield: For Vic Johnson we are substituting Mr. F. J. Johnson, who is here.

Johnson: I am not very familiar with the Clackamas River, myself -- Vic Johnson used to keep all those records, but all indications are that it will be an extremely low year, -- he told me about equal to 1936, or maybe a record low.

Peterson: Well, 1936-37, as we call it, starting in July, 1936, and ending March, 1937, has been found to be the critical year for the Northwest Power Pool as a whole. It isn't the worst year in each locality. Some localities have had worse years, but, as a group, 1936-37 is the worst year of record, and if it is that way with the Clackamas, it ties in with the condition we expect in many other regions in the Northwest Power Pool.

I believe that is all our section has to offer, Mr. Work.

Work: Thank you, Mr. Peterson.

Canfield: I saw Mr. Codd signaling.

Work: Yes, I thought I saw Mr. Codd bursting with some information, there.

Codd: It is an apology. One of our representatives is leaving shortly on the train, and we must get together at the Weather Bureau office to discuss some matters. If the group will excuse the Weather Bureau, we will go on with our other work. It has been a good meeting.

Work: We are sorry you can't stay.
These men have come in all the way from far points and we need to work over some of our river district problems.

Well, your group is excused.

Thank you.

(Mr. Codd and several other gentlemen here left the room.)

Now, we will get into this effect of water shortage on agricultural planning and farm production problems of various sorts. Here today is Professor Breithaupt, the Extension Economist from Oregon State College. He has with him some very able support in Mr. E. R. Jackman, Farm Crop Specialist, and Arthur King, the Irrigation and Soils Specialist at Oregon State College. Mr. Breithaupt, we will turn it over to you.

The question that has been presented here has been discussed somewhat already, and I promise you that we will be brief and not detain you very much longer on this section of the program.

I was interested in Mr. Work's outline of water shortage effect on prospective hay production in Oregon. I made some further inquiry on this from one of the previous speakers from Idaho. Mr. Criddle, would you care to repeat something along the line that you told me about Idaho?

Well, I was asked what the reduction in hay would be in Idaho. We have made no direct estimate of the reduction in hay in Idaho. We merely stated that water supply there to about a third of the irrigated land will be reduced 25 percent, or have 25 percent water shortage, so perhaps the hay production will be reduced, oh, from a tenth to a twelfth, or somewhere along in there. That is about the only basis we have to go on.

In Washington the crop reduction on the irrigated land will not be so great. The Yakima Valley comprises a big part of the irrigated area, and they have storage reservoirs which will, in general, see them over. The other areas, such as Wenatchee and Okanogan, have more water than they use anyway, so they should not be hurt seriously. Of course, there are shoestring areas up along those smaller creeks which will be hurt.

Thank you, Mr. Criddle.

The subject, of course, was the prospects here in the Pacific Northwest, and I doubt whether any of us who are listed on this agenda have made a study, outside of the State of Oregon and not too much there, in relation to the prospective water supply. Is there anyone else in the audience, except those of us who are listed, here, Mr. Jackman, Mr. King, Mr. Nielsen, Mr. Miller, and Mr. Laythe, who have anything to contribute on the situation in Washington and Idaho, in addition to what Mr. Criddle has told us? (Pause) If not, I think we will have to confine our remarks from here on primarily to the State of Oregon. Mr. Work, did you have anything further that you wanted to say at this point?
Perhaps Don Williams or Karl Kohler, who have connections with Soil Conservation Districts in various parts of the Northwest, have information to offer.

The general situation as outlined here today applies in those areas without storage in which we are working. Farmers there certainly are looking forward to a short water year in the late part of the season. There is a large acreage of that type of irrigation in the Northwest.

I might say on behalf of Mr. Nielsen, who couldn't be here, that he feels that we are going to need to make considerable study of this and other information as the season advances in order to estimate the total hay supply that is going to be available next winter in relation to the livestock population. There is some apprehension about that situation, and what you have said to us, Mr. Work, increases that feeling. Mr. Nielsen's Service will, as of May 1, make an estimate of the carryover hay supply. We anticipate that may be somewhat greater than a year ago, and particularly, perhaps, in those areas that are most threatened with the short run-off this year, the wild hay sections. I say in general. There will be exceptions, but at least the carryover hay from last year's crop is expected to be some offsetting factor to the probable decrease in hay production this year. Also, as of June 1, Nielsen's Service will make the first estimate of this year's probable hay production. Experience of past years has shown that this June 1 estimate is sometimes erroneous one way or another, because later weather conditions have a great deal of effect on the final out-turn of the hay crop, which, for the most part, is made during July but partly right on through the fall. I would sum up what you have told us, Mr. Work, in this way: that it looks like a short crop of wild hay and a short crop of late cutting alfalfa.

Now, unless someone has some other comment to make by way of summarizing the prospects, we will call upon Mr. Jackman and Mr. King for their comments as to effect of this water shortage upon planning this year's agricultural operations.

Well, the emphasis here, so far as agriculture is concerned, has been on the hay supply. I have these observations: A drought year does not affect the hay supply as much as it does some other crops. We have had years in Oregon when a short water year has cut our grain crop just almost exactly in half as compared to good water years. I don't believe that we have ever had a year in the history of the State when a dry year or short water year made more than about a 20 percent reduction in hay from normal for a good water year. But the difficulty with that is, a hay shortage doesn't work in the same fashion as a short grain crop. If a man has a short grain crop, - has his grain crop cut in two, for example, by drought, - he has just half as much wheat or barley or whatever, to sell, but he usually manages some way to get along; but if the State's hay supply should be cut twenty percent, the supply of some men will be cut 50 percent. If a
man's hay supply is out as much as 50 percent, he is in a bad
fix, because his stock keeps on eating hay just the same. He
can't ration out his hay to his stock that way, and he has either
got to go someplace else and get some hay, or ship his stock
someplace else, or sell it. And, of course, if his hay crop is
cut in half, then that means that most of his neighbors' crops
probably are, and people all over that part of the United States
probably also have a short hay crop, so that there isn't any
place else to go to get any more hay, and there isn't any good
place to ship his stock. I am afraid we are in somewhat that
predicament this coming year. The Boise Valley, in Idaho, for
example, has a marked influence upon the hay condition in this
state. We always ship, oh, 10,000 tons or more of hay out of
Malheur County over to Boise Valley; and this year I suspect,
the way things are in Idaho, that they may want to get a lot more
than that. Then from the other side of the state we always ship
from ten to fifteen thousand tons of hay down into California,
and conditions there in the Sacramento Valley, although that
hasn't been mentioned here today, are rather bad this year. Their
pasture is short and everything else is short down there, and I
expect the California people will want to ship their stock up
into Klamath, and they will want to come up into Klamath to buy
our hay, so that we will have extra drains on our hay supply and
apparently loss of it to offer. A consoling factor is that the
Willamette Valley is likely to have, if the weather lets them
cut and handle it, the largest hay crop that it has had for a
long, long time. A series of circumstances has developed that
make, oh, forty, fifty thousand additional acres available for
cutting for hay in the Willamette Valley this year, over and
above what we have had in the last few years.

So far as other crops are concerned, shortage of irrigation water
does not affect them so much. Potatoes are absolutely dependent
upon water, but if a man has any water at all, if he is growing
some potatoes he will neglect his other crops and put the water
that he does have on the potatoes, so even if he does only have
25 or 30 percent of water, he will manage some way to water the
potatoes and let the rest of his crops go.

Our seed crops in the main are not heavy users of water, so they
usually get enough water. Lack of water does not reduce seed
crop yield the way it does other crops, so we probably will have
a normal seed crop yield and probably a normal potato yield on
the reduced potato acreage that we will have this year. The main
effect of any shortage of water will be, as has been brought out
time and again, here, on hay. It is going to be up to dairymen
here in Western Oregon and livestock men in Eastern Oregon to
either be doing something pretty soon with some of their surplus
stock or making some arrangements.

Breithaupt: Thank you, Mr. Jackman. Now, let's have your viewpoint, Mr. King.

King: You might be interested in this comparison on the basis of acreage.
I don't know whether this will check with Work's estimate. He may
have a closer one than I have, but it looks as if about 200,000
acres in Oregon are going to have an ample water supply; about
800,000 are going to be short to some degree, but, as Mr. Jackman indicates, the 800,000 acres are largely hay land and connected up with the beef cattle.

Now, there is a more optimistic viewpoint that can be taken on what will likely happen in some areas, and more than you might think; that is that a short water year may mean a higher hay yield, - a higher hay yield than farmers want to admit at this time of the year. That just happens time and time again, in two areas in particular, Baker Valley and Wallowa Valley, where you have a pessimistic outlook, low water years have been the best yield years, because when they have water they use it and often overdo it.

Work: I see we are getting into a drainage problem now.

King: Does that check?

Work: Your area figures don't check very closely with ours. Do you want to have our acreage figures?

King: I should like to have them.

Work: I will get them out. Now, you just recognize two qualifications on the water supply. One was ample and one was deficient.

King: Yes.

Work: We tried to recognize three, this year, and, in some areas I guess we should have recognized more but, after all, we are forecasting and why identify 4 or 5 gradations of water supply when it might turn around and rain, resulting in just one water supply. We did recognize "good", which means adequate, ample, or plenty; "fair", which we have chosen to call generally adequate but somewhat short late in the season -- in other words, there would probably be a mild reduction in production, there, of crops requiring later water; and "deficient" -- that is, just out-and-out deficient, going to be short. Of the million forty-nine thousand irrigated acres in Oregon we have classed 500,000 as "good" and a little over 500,000 as "fair" to "deficient." In the deficient class we found 263,000 acres, or pretty close to a quarter of the State's irrigated acreage, which is a little more optimistic than the figures you have in mind.

King: That is better than I would figure, but your figures are on a comparative basis with past years. When one considers that about 700,000 acres of Oregon irrigated land are always short of water, we may not be so far apart.

Breithaupt: That compares with the data from Idaho: deficient on about a quarter of the acreage, I believe you said.

(Mr. Criddle nodded.)

Breithaupt: And of course that doesn't mean a failure on that quarter does it?

Work: Well, no, but it could on some of it. As Mr. King says, an object of meetings such as this is to stimulate interest on the part of
the farmers in conserving, saving and best utilizing the available water supply. If the farmers will get in and clean their ditches and adopt all sorts of water-conserving practices, this limited water supply will go much farther, and perhaps the reduction in production will not be so great as we fear it might be.

Breithaupt: I wonder, Mr. Work, if you could tell us the technique followed in making those estimates of hay reduction?

Work: Yes, I will tell you. It isn't necessarily our exact job to do that, you understand, but in many of our forecast meetings probable effects of water shortage came up for discussion, and we became rather interested in accumulating a rough estimate of the possible reduction in hay production, since each committee resolved the forecast of the probable water supply into such terms. We had with us in those meetings county agents, who are very well informed, and irrigation district superintendents, who are likewise well informed. We would ask them, by way of illustration: "All right, water supply this year evidently is going to compare with 1926. Assuming the water supply develops about as predicted, and recalling your situation here in 1926-- or 1934 or 1931, whichever year it compared to most closely -- "what would be your estimate as to the probable reduction?" "Oh, well," they'd say, "we didn't get any third cutting that year, and our second cutting was cut just about half. So on that basis, it appears the alfalfa hay production would be cut approximately 20,000 tons." That was the modus operandi there. I am not submitting these estimates as being at all polished. They are simply indicative of what we found. Does that answer your question?

Breithaupt: Yes. That is interesting. You have talked around a round-table and compared notes and judgment and arrived at that conclusion, as your report states, subject to what the weather may be later on to a considerable degree.

Work: Yes.

Breithaupt: Mr. Burtner, do you have any comments you would like to add?

Burtner: I am just listening.

Breithaupt: Anyone else have any comments on this subject of probable agricultural production and agricultural planning? (Pause)

Canfield: Mr. Chairman, I was wondering if we shouldn't hear from the representative of the Forest Service, Mr. Phelps, here in this section of the meeting, as to possible effect of 1944 water supply on tree growth or range in the mountains?

Phelps: The Forest Service as an organization has not so much immediate interest in the effect of rainfall on tree growth as on the current fire season. Weather, to the Forest Service, usually means weather in terms of the fire danger. It is true that the hay crop in Eastern Oregon is important to us from the standpoint of range conditions, and precipitation as it affects tree growth is important because dry years slow up tree growth to some extent,
but there isn't much we can do about it. The thing that does affect us is the kind of a fire season we are going to have. I have been much interested in hearing the applications of all these data to the other things -- power, irrigation, crops and flood stages of the river -- but apparently the data assembled here aren't of much application to our problem because what we are interested in is rainfall and lightning during the summer months, particularly from July 1 forward.

As you know, our major fire season in the Pacific Northwest starts about June 20 to July 1, and the severity of that season is largely dependent upon drought conditions, lack of rainfall. Late spring rains give us green grass and green cover under the trees. This delays the impact of the fire season. Drought during July and August dries up the grass, and particularly on the west side it has a cumulative effect in drying out the forest cover, the duff. Now, the duff on the west side in the Douglas Fir region is thick. Sometimes it is 16, 18 inches thick on the forest floor. Lack of rainfall as the season advances dries that duff gradually. The farther down it dries it, the worse fire situation we have; and the harder fires are to control in what we call the "heavy duff area;" so that when we have extended periods of drought in July, August, and running into September, we get the accumulation of that drying out of the duff during the late fire season, which makes fires hard to control on the west side, and the chances of a fire getting away will rise in direct proportion. Then, of course, the situation is complicated with lightning and with periods of east wind which creates our serious fire weather on the west side. We get a great deal of cooperation and help from the Weather Bureau in predicting lightning storms.

Altogether, looking at the picture that has been drawn here today, it seems to me that the Forest Service is just a little bit different. We have different weather factors to consider than others of the group here; nevertheless, this Conference has been very interesting, indeed, and I have been very happy to attend.

Wahle: I should like to ask if anyone here has made a study as to the correlation between river run-off and these various factors that have been brought up, or the fire season in the forest. There must have been. It suggests itself to my mind that there might be some correlation there, and I wonder if anyone has made any research along those lines.

Breithaupt: As far as I know, it is only partial, not a very thorough study.

Wahle: A study of that kind, to be of any value, would of necessity need to be complete.

Breithaupt: And go back quite a good many years. -- That is one thing Mr. Nielsen asked me to say to Mr. Work; that he would like access to your historic data, back as far as possible, in order that he might attempt to correlate hay yields and production.
Work: What sort of data? Stream flow or snow cover?

Breithaupt: Both snow cover and stream flow data. He has undertaken to correlate hay production with data in his own office on condition of pastures and ranges at this time of the year, but that hasn't been too fruitful. He finds too many exceptions where it just works contrary to what you might expect.

Work: Does he desire that for the Columbia Basin?

Breithaupt: State of Oregon only. He works only in the State of Oregon, but no doubt the other man in his Service would be interested in it in Idaho and Washington. I expect they would be. Ordinarily, they depend upon surveys made a month or two later than this to make their estimates, but in a critical situation such as this it warrants some special study, and we would like to see such a study made as has been suggested. I believe your data, if they go back far enough and can be related to the production, would be of assistance.

Work: How far back should it go?

Breithaupt: Well, I should like to see them go clear back to about 1917 or 1918 and relate it to the data that he has extending back that far.

Work: The snow survey records in Oregon don't go back anywhere near that far, but of course the stream flow records go back much farther.

Canfield: Continuous records of flow near The Dalles since June 1878; on the Willamette River at Albany since January 1892.

Wahle: It just occurred to me, the possibility of using, oh, for example, the Columbia River record as the key to this whole Northwest, that we might find some correlation in there that would be of definite value so that we could actually have something we could lay our finger on rather than making just a vague estimate of the situation.

Breithaupt: Yes. And, as Mr. Jackman brought out, this matter of prospective hay production isn't confined to any one locality, or to small localities. It is a problem for the entire Columbia Basin, for the entire Pacific Northwest and even including California, as he brought out. Hay deficiencies in one state affect conditions in the other states, and they are more or less common, I expect. As Mr. Jackman brought out, reports reaching us from California are quite disturbing, - more so than up here.

Bocardo: One point brought out here may have very little bearing on the whole picture, but as a matter of interest, I recall mention this morning was made that all of the low lands along the Columbia now could be safely farmed to their complete capacity. I would like to know about how many acres in Oregon and Washington are affected by that low land overflow that sometimes takes them out of production until very late in the year?
Breithaupt: Kenneth Miller here? (Pause) He was one of our pinch-hitters. He should answer that one.

Canfield: Mr. Fisher made that statement. He had in mind diked off areas adjacent to the Columbia River below Vancouver.

Bocarde: There is a little between here and The Dalles, too, but very small.

Work: Perhaps Mr. Hon can give us some information on that. Mr. Hon is the Manager of one of the drainage districts down the river.

Hon: I am Manager of the Scappoose District, which includes about 5,000 acres. I have no information as to the total such acreage.

Canfield: Well, a year ago the probable high stage was a very serious consideration. I rather gather from Mr. Fisher's statement that you shouldn't anticipate any such serious condition this year. Is that the case?

Hon: Well, we don't on our District if these predictions are right. That is what I was interested in today. Last year we operated our pumps until it just about "broke" us. It is much better this year. (Laughter)

Breithaupt: There is an uncertain acreage of marginal land there that can be utilized apparently this year much more safely than last year. There might be something worthwhile to check into.

King: The acreage is rather small, now. Most of the worthwhile parts of the land have been diked. They would be affected only in the extreme peak year.

Breithaupt: Any other comments? (Pause) Well, Mr. Work, we appreciate the opportunity to attend this meeting.

Work: Mr. Breithaupt, believe me, the Committee appreciates your coming up here from Corvallis to do as the rest of us have done, - put in your fifty cents' worth.

Is Mr. Darlington here? Yes. Well, you have been sitting back, Mr. Darlington, chuckling to yourself and figuring you were going to get out of here without being called on, I am afraid.

Darlington: I didn't come here to do much talking. I came here to listen and to get a little information. It is my job with the War Production Board to assist the utilities here in the Northwest in securing necessary materials to carry the power loads that come on, increasing every year, and especially the heavy war loads that we have to contend with these days. Being connected, as I am, with a water power area, it is, of course, vitally interesting to me to know what the water supply for the coming year is going to be. That is the reason I nosed into this meeting today, to try and find out what everybody thought of the water supply for the coming year. I gather that we may have a little water, and the situation may be a little bit better than the worst year, but still we should look for some pretty dry spots.
Evidently we may have to conserve our reservoirs to squeeze through, but still we hope we will make it. We may have to use a little fuel, perhaps more than usual, because in certain areas we may not have quite so much water as we did last year, which was a very, very favorable year from the standpoint of water. I enjoyed being here.

Work: We are glad to have you with us, Mr. Darlington. You were with us last year, I recall.

Darlington: Yes, I was here last year, too.

Peterson: Yes. I don't think we mentioned the fact that Mr. Darlington is connected with the War Production Board, and he has been very helpful and active in solving some of our problems for us in the Northwest Pool.

Work: Yes. I should have mentioned that. -- Gentlemen, the time is drawing near for conclusion of our session. Miss Mulvey has taken a complete record of the meeting, which will be made available to each of you, provided you have signed a registration card giving your mailing address. We will get it out as quickly as we can so you can have the transcription for your files. Now, has anyone in the room anything further to add to the record?

Peterson: Is it your plan that we should mark up the transcript and send it back to you, Mr. Work?

Work: That is right.

Peterson: I wonder if we could put down what we would like to have said instead of what we said. (Laughter)

Canfield: That is common practice, Mr. Peterson, I am sure.

Frame: Is it possible to have some of those transcripts sent to some that didn't come, such as Mr. Davis?

Work: Oh, yes. -- It has been our custom to send copies out to the men who have taken the most active part in the discussion so they can add the good stories they forgot to tell, or otherwise (Laughter), and then I have taken the liberty of editing the comments of everyone, not to change the substance or the facts, but merely to freshen up a few little rough places that may occur. If there are no objections to that procedure, we will follow it again this year.

There is no further business, so this meeting stands adjourned.

(The foregoing meeting was thereupon adjourned at 3:13 o'clock p.m.)
# Roster of Attendance

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March 25, 1946

Mr. R. A. Work
Project Supervisor
Soil Conservation Service
P. O. Box 1149
Medford, Oregon

Dear Mr. Work:

As requested in your letter of the 21st, I am sending one copy each of the Colorado River Water Forecast Committee meeting, Los Angeles, April 1945, to E. R. Jackman and E. C. Gwillim, at Oregon State College, Corvallis.

Very truly yours,

R. L. Parshall
Senior Irrigation Engineer

RLP:ds
Mr. R. L. Parshall
Senior Irrigation Engineer
Colorado Experiment Station
Ft. Collins, Colorado

Dear Mr. Parshall:

Have just returned from an extended field trip to the pleasure of perusing the report of your Colorado River Water Forecast Committee. The article by Wilm is of particular interest to people in Oregon concerned with management of lodge pole stands. Will you kindly furnish a copy of the report to:

E. R. Jackman
Oregon State College
Corvallis, Oregon

E. C. Gwillim
Oregon State College
Corvallis, Oregon

Very truly yours,

R. A. Work
Research Project Supervisor

cc: ERJackman
ECGwillim