86th Congress }
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COMMITTEE PRINT NO. 25

WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

RIVER FORECASTING AND HYDROMETEOROLOGICAL ANALYSIS

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS
FIRST SESSION

NOVEMBER 1959

Printed for the use of the Select Committee on National Water Resources

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SELECT COMMITTEE ON NATIONAL WATER RESOURCES

(Pursuant to S. Res. 48, 86th Cong.)

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STATEMENT BY THE CHAIRMAN

OCTOBER 26, 1959.

To the Members of the Select Committee on National Water Resources:

The Select Committee on National Water Resources is directed by the provisions of Senate Resolution 48 to give its attention to, among other things, the character of legislation which would encourage the adoption of new technical methods and improved processes for increasing the usefulness of available water resources. In addition, the committee is concerned with seeing that appropriate provisions are made in our water resource development programs for the future for reducing the ever-mounting damage resulting from floods.

To a very considerable extent knowledge of climatic conditions and riverflows and their relationship makes it possible to use and control water to the best advantage. In recognition of these matters the Congress has authorized the Weather Bureau of the Department of Commerce to establish a program for forecasting riverflows for the purpose of reducing flood damages and prevention of loss of life from floods. Along with this function the Weather Bureau carries out a very extensive program of hydrologic and hydrometeorological analyses in connection with studies by other agencies of future water resource developments.

In order to assist the committee in its consideration of these matters I asked the Weather Bureau to prepare a report covering future needs and possibilities for improvement in river forecasting and hydrometeorological analysis, giving the Weather Bureau's recommendations as to future action which might be taken in these fields as a means of improving the usefulness of available water supplies.

The report prepared in response to my request will be of interest to you, to the other Members of the Senate, and to others concerned with finding solutions to the Nation's water resources problems. Accordingly, I am having the report printed as one of our committee prints dealing with the aspects of water resources activities which are being considered by the committee.

ROB'T S. KERR,
Chairman, Select Committee on National Water Resources.

COMMUNICATIONS

JULY 20, 1959.

Hon. FREDERICK H. MUELLER,
Acting Secretary of Commerce,
The Department of Commerce, Washington, D.C.
(Attention: Francis W. Reichelderfer, Chief of the Weather Bureau.)

MY DEAR MR. SECRETARY: Reference is again made to my letter of June 15, 1959, concerning the work of the Senate Select Committee on National Water Resources. In addition to the report requested on weather modification we believe there are other technical methods and improved processes for increasing the usefulness of available water resources on which the comments and suggestions of the Weather Bureau would be helpful to the committee.

As examples, we have in mind the more effective operation of reservoirs, powerplants, irrigation projects, and other water facilities, through improvements in forecasting stream flow, and making better use of other hydrologic data.

As the Weather Bureau is engaged in both a streamflow forecasting program and in hydrologic investigations basic to water resources planning, the committee would like to have a report prepared by that agency covering the following subjects:

1. The needs and possibilities for improvement in the accuracy and usefulness of forecasts of riverflow—daily, seasonal, and flood.
2. The needs and possibilities for improvement in the availability of basic data for use in the study of water resources problems.
3. The needs and possibilities for improvement in the accuracy of quantitative forecasts of precipitation as a basis for making more accurate streamflow forecasts.
4. Other comments and suggestions which the Weather Bureau might wish to make with reference to increasing the usefulness of available water supplies.

To the extent practical, estimates of cost-benefit ratios for the above practices should be included, together with estimates of potential increases in usable water supplies by river basins.

We would like this material to be covered in a summary report of not more than 10,000 words, with whatever tables, charts, appendixes, and graphic illustrations as may be considered necessary. It would be most helpful if this information could be furnished the committee by October 15, 1959.

The committee staff will be glad to discuss any problems which may arise in the preparation of the report with representatives of the Weather Bureau.

Sincerely yours,

ROB'T. S. KERR, *Chairman.*

THE SECRETARY OF COMMERCE,
Washington, D.C., October 16, 1959.

Hon. ROBERT S. KERR,
Chairman, Senate Select Committee on National Water Resources,
U.S. Senate, Washington, D.C.

DEAR SENATOR KERR: With this letter I am transmitting the Weather Bureau's summary report on the role of river forecasting and hydrometeorological analysis in water resources, as requested in your letter of July 20, 1959. We appreciate very much the opportunity to assist the committee in its work and stand ready to provide greater detail than contained in the report whenever necessary.

By agreement with Mr. Schad of the committee staff, 50 copies of the summary report are being furnished at this time, and more can be made available.

Sincerely yours,

PHILIP A. RAY, *Under Secretary of Commerce.*

Enclosure.

PREFACE

The programs of the Weather Bureau related to water resources can be discussed under two main headings: "River Forecasting" and "Hydrometeorological Data for Planning." The following report is divided in this fashion and, for purposes of summary, further divided into shorter discussions under brief statements of "Facts" and "Needs." The latter are listed in a table of contents, which serves also as an outline or thumbnail summary of the report.

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RIVER FORECASTING AND HYDROMETEOROLOGICAL ANALYSIS

I. RIVER FORECASTING

Fact 1

The national flood forecasting service is provided by the Weather Bureau

Since its establishment in 1891, the Weather Bureau has had the national responsibility for issuing flood warnings to the public. The main purpose of this program has been reduction in flood damages and in loss of life. In addition, the river forecasting techniques and facilities required are the basis for many other services, such as:

1. Daily forecasts of river stage or flow for use in reservoir operations; for regulation of power, water supply and discharge of industrial waste; for navigation; and for river and riverside industry and construction.
2. Extended forecasts of low-water stages or flow, for navigation and planning of special releases to maintain required minimum flow.
3. Forecasts of seasonal and water-year runoff, in regions of snow accumulation, for crop planning and irrigation, and for hydroelectric and water-supply operations.
4. Forecasts of natural flow on regulated streams as a guide to control operations and evaluation of their effectiveness.
5. Forecasts of river-ice formation and dissipation for shipping and riverside industry.
6. Data for hydrologic and hydrometeorological analyses, required for planning.

Figure 1 is a schematic outline of the basic operations and facilities involved in the program.

FIGURE 1

RIVER & FLOOD FORECAST AND WARNING SERVICE

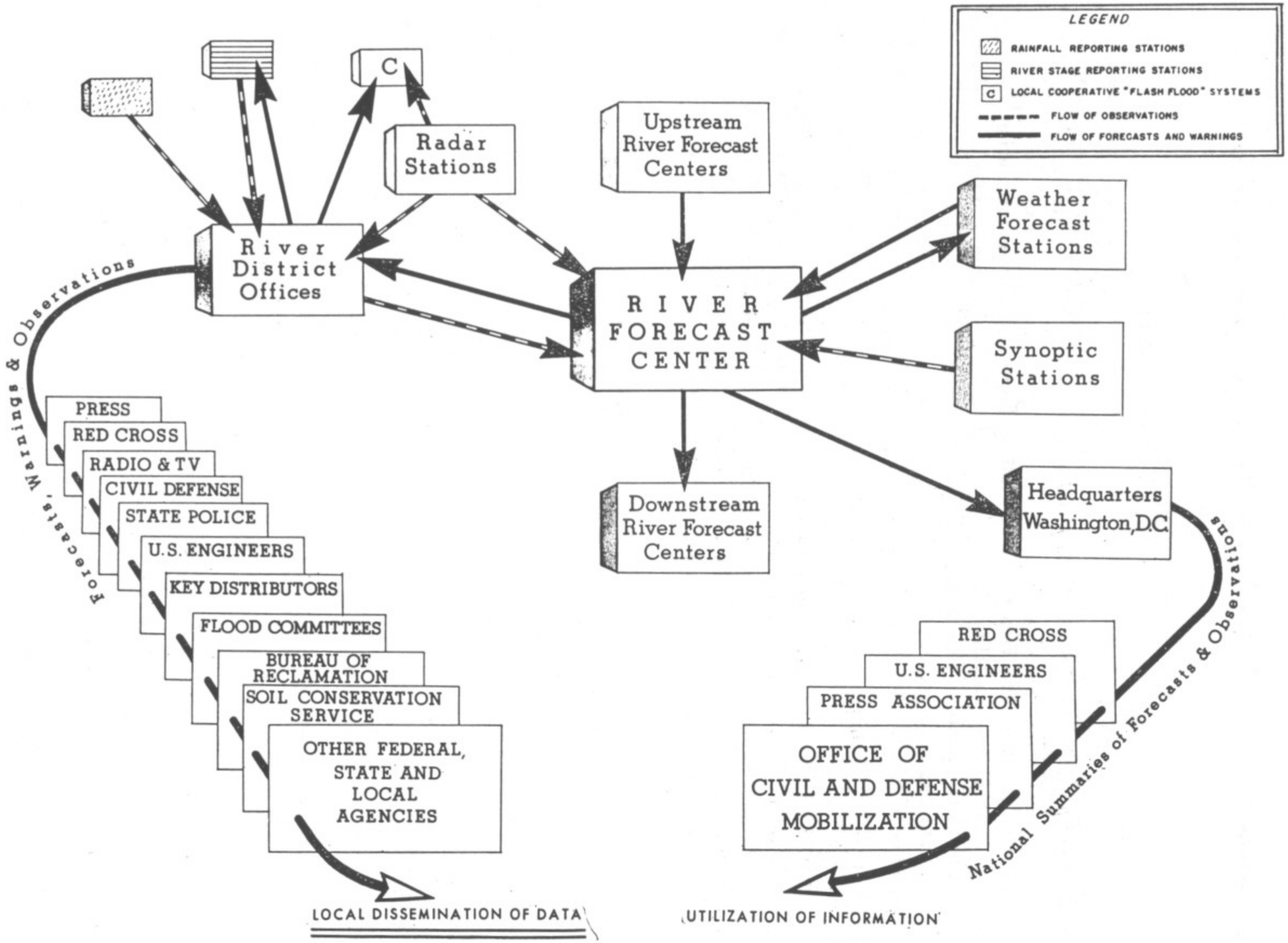

FIGURE 2


SOME PREVENTIVE ACTIONS RESULTING FROM FLOOD WARNINGS
SANDBAG FILLING
REINFORCING DIKE
EVACUATION OF MOVABLE GOODS
MOVING HOUSEHOLD GOODS TO HIGHER GROUND
RAISING LEVEES
DAVIS FOOD
BARRICADING BUILDINGS AGAINST FLOODS

Fact 2

Flood forecasts reduce property damage and loss of life

Flood damages are prevented or reduced by actions and measures taken as a result of advance warnings. They include evacuation or removal of people and goods; flood fighting by temporary works, such as barriers, sandbagging, boarding up, or coating or packing machinery in grease; and rescheduling of operations or rerouting of transport. Some actions are illustrated in figure 2. An exhaustive tabulation on relative susceptibility of flood loss types to reduction by emergency measures, taken from Gilbert F. White's "Human Adjustment to Floods" (1945, p. 170–172), is contained in table 1.

Table 1.—*Relative susceptibility of flood losses to reduction by emergency measures based on flood forecasting*

Class of loss [1]	Degree to which loss may be reduced by emergency measures based on timely and accurate flood forecasts			Emergency measures
	Large	Medium	Small or none	
Agricultural:				
1. Crops:				
(a) Unharvested mature crops.		X		Rescheduling; early or more rapid harvest.
(b) Decrease in yield			X	
(c) Reseeding perennial crops.			X	
(d) Crops not planted			X	
(e) Replanting of crops			X	Rescheduling; delay in planting.
2. Stored crops	X			Removal.
3. Orchard			X	
4. Farm timber			X	
5. Livestock and livestock products.	X			Do.
6. Residence. (*See* "Urban residential.")				
7. Furnishings	X			Do.
8. Personal belongings	X			Do.
9. Other farm buildings			X	
10. Farm machinery and equipment.	X			Removal, protection.
11. Automobiles, trucks, wagons, boats.	X			Removal.
12. Fences, roads, and outdoor improvements.			X	
13. Drainage and irrigation works.			X	
14. Land			X	
15. Nonfarm income			X	
16. Evacuation and reoccupation.			X	Rescheduling.
Urban residential:				
1. Residence:				
(a) Foundation			X	
(b) Superstructure			X	
(c) Improvements (fixed).		X		Protection.
(d) Decorations			X	
2. Furnishings	X			Removal.
3. Personal belongings	X			Do.
4. Garage and other buildings.			X	
5. Automobiles, wagons, trucks.	X			Do.
6. Grounds and outdoor improvements.			X	
7. Loss of property income			X	
8. Evacuation and reoccupation.			X	
Retail and wholesale commercial:				
1. Building. (*See* "Urban residential.")				
2. Furnishings	X			Removal.
3. Equipment	X			Removal, protection.
4. Stock of merchandise	X			Removal.
5. Minor buildings			X	
6. Automobiles, wagons, trucks, etc.	X			Do.
7. Grounds and improvements.			X	
8. Business interruption:				
(a) Production of goods and services.		X		Rescheduling.
(b) Productive equipment and supplies.		X		Protection, removal, rescheduling.
(c) Excess cost of delayed sales.			X	
9. Evacuation and reoccupation.			X	

See footnote at end of table.

Table 1.—*Relative susceptibility of flood losses to reduction by emergency measures based on flood forecasting*—Continued

Class of loss [1]	Degree to which loss may be reduced by emergency measures based on timely and accurate flood forecasts			Emergency measures
	Large	Medium	Small or none	
Manufacturing:				
1. Buildings. (*See* "Urban residential.")				
2. Office furnishings and records.	X			Removal.
3. Plant machinery		X		Removal, protection.
4. Stock of raw materials or finished goods.	X			Do.
5. Minor buildings			X	
6. Automobiles, wagons, trucks, etc.	X			Removal.
7. Grounds and improvements.			X	
8. Business interruption:				
(a) Production of goods		X		
(b) Productive equipment and supplies.		X		
(c) Excess cost of delayed production.			X	
9. Evacuation and reoccupation.			X	
Public buildings and grounds:				
1. Buildings: (See "Urban residential.")				
2. Furnishings	X			Do.
3. Equipment		X		Removal, protection.
4. Stocks of supplies	X			Removal.
5. Public records, books or other valuables.	X			Do.
6. Minor buildings			X	
7. Grounds			X	
8. Automobiles, wagons, trucks, etc.	X			Do.
9. Evacuation or reoccupation.			X	
Public services:				
1. Indoor equipment, housing and grounds.		X		Protection.
2. Outdoor stationary equipment.		X		Do.
3. Outdoor mobile equipment.	X			Removal.
4. Underground facilities		X		
5. Lines, mains, tracks, poles, etc.			X	
6. Emergency service	X			Rescheduling.
7. Evacuation and reoccupation.			X	Do.
Railroads:				
1. Minor buildings			X	
2. Outdoor stationary equipment.		X		Protection.
3. Roadway			X	
4. Rolling stock	X			Removal.
5. Goods in transit	X			Rescheduling, removal.
6. Emergency service		X		Rescheduling.
7. Evacuation and reoccupation.			X	Do.
City streets and highways:				
1. Roadway			X	
2. Cost of rerouting traffic		X		Rescheduling.
3. Cost of fighting flood		X		Do.
4. Cleanup			X	
Bridges:				
1. Piers and abutments		X		Protection.
2. Superstructure		X		Do.
3. Approaches			X	
4. Utilities			X	
Miscellaneous river structures: Dams, revetments, levees, etc.			X	

TABLE 1.—*Relative susceptibility of flood losses to reduction by emergency measures based on flood forecasting*—Continued

Class of loss[1]	Degree to which loss may be reduced by emergency measures based on timely and accurate flood forecasts			Emergency measures
	Large	Medium	Small or none	
Relief expenditures:				
1. Evacuation and rescue work.		X		Rescheduling.
2. Emergency supplies		X		Do.
3. Administration on rescue camps.		X		Do.
4. Care of sick and injured		X		Do.
5. Policing		X		Do.
6. Flood fighting		X		Do.
7. Cleanup (public)			X	

TABLE 1.—*Relative susceptibility of flood losses to reduction by emergency measures based on flood forecasting*—Continued

Class of loss[1]	Degree to which loss may be reduced by emergency measures based on timely and accurate flood forecasts			Emergency measures
	Large	Medium	Small or none	
Public health:				
1. Sickness and injury		X		Rescheduling.
2. Emergency public health activities.		X		Do.
3. Loss of life		X		Removal, reduction in rescue work, improved public health work.

[1] Classification from National Resources Committee, report of the Subcommittee on Flood Damage Data, Mar. 15, 1939, mimeographed.

Figure 3

FLOOD WARNINGS REDUCE PROPERTY LOSSES

The Pittsburgh Press

July 22, 1956

Flood Tip-off Saves District $8 Million

Advance Warning Last March Worth $4½ Million to City

The old saw about an ounce of prevention during the heavy floods of last spring turned out to be worth over $8,000,000.

Rampaging waters along the Pittsburgh river network poured out a toll of $2,500,000 destruction throughout the ... completed ... flood

Flash-Flood Warning System Cut Loss to Minimum, Survey Shows

By PAUL R. JORDAN
Associated Press Staff Writer

Frankfort, Ky., June 6 (AP)—The bustling little town of Martin was cited Friday as a prime example of how Eastern Kentucky's new flash-flood warning system was used successfully last month.

The mountain section was struck by near-... floodwaters in early May, centering mainly ... River basin.

... beginning at 30 feet. With water standing at 37.6 feet at 9:53 a.m. May 7, the Cincinnati office forecast a crest of 44 feet. A crest of 42.7 was reached at 1 a.m. May 8, about 15 hours later.

Halbert said Martin citizens were "very gratified with the results of the flood-warning system because they know it saved them thousands of dollars."

In Martin proper, he said, 16 business places and 25 homes were flooded. But because of the forewarning, he added, no damage was done to movable objects such as merchandise and fur-

... too, were State

The Cheraw Chronicle

PUBLISHED EVERY THURSDAY AT 14 FRONT STREET, CHERAW, S. C.

Highest Since 1954

Pee Dee River In Flash Flood But Warnings Save Livestock

Pee Dee River went on a ... yesterday, reaching to its ... level since 1954 and ap- ... the record height ... the great flood of

Mrs. Bessie Page, local weather observer, said that she received first warning from Charleston Monday and that she hastily notified farmers, owners of livestock and others with interests along the river banks. Loggers, lumber-

Data on savings due to flood warnings, collected by the Weather Bureau for the period 1941–51 (adjusted to 1951 price levels), show:

Annual damages	$256, 612, 863
Annual savings	28, 763, 493

Thus, about 10 percent of potential flood damage (damage plus savings) are saved by flood warnings. Applied to the changing mean annual damage figure obtained by the Weather Bureau, this 10 percent gives a current saving in excess of $30 million. Figure 3 reproduces specific press items on flood damages and savings, including a detailed survey (in the Pittsburgh area) indicating how conservative the 10 percent estimate may be, especially in urban areas. In any case, with the current cost of the Weather Bureau's flood forecasting service at less than $1,500,000, the benefit-to-cost ratio is over 20 to 1.

Loss of life in severe floods since 1902 has been as high as 467 in the Ohio River flood of March 1913—a billion-dollar flood in property damage at current dollar values. In another billion-dollar flood—in the Kansas-Missouri area, June-July 1951—only 28 lives were lost. Part of the difference is the result of an improved flood warning system. An analysis of 10-year moving averages of annual loss of life shows a gradual decrease from 100 to 80 per year in the last 10 years. A perfected flood warning system should eliminate all loss of life in floods except that resulting from negligence or failure of communications, probably a 90-percent reduction—to about a loss of 10 lives on the average per year.

Fact 3

Flood damages are increasing as a result of increased occupancy of the flood plain

The upward trend in flood damages is a recognized fact. To quote from Hoyt and Langbein's "Floods" (1955, p. 90):

> The evidence, therefore, strongly suggests an actual increase in amount of flooding in the 50 years of record since 1903 * * *. Of the increase we may ascribe * * * 30 percent to an increase in building and other uses on flood-hazard lands.

Quoting from Murphy's "Regulating Flood Plain Development" (1958, p. 12):

> The tentative conclusion reached was that the rate of increased development in urban flood plains was such as to cause a potential damage increase in excess of 1.5 percent per year.

Table 2, reproduced from White's "Changes in Urban Occupance of Flood Plains in the United States" (1958, p. 207), gives typical figures of the marked growth:

Table 2.—*Selected areas—percent net change in aggregated structural units in the flood plain circa 1936–57*

Area	Population estimated percent change 1936–57	Aggregate structural units		Percent net change	Percent change per year
		Circa 1936	Net change		
Augusta	56	8, 061	1, 974	24	1. 14
Binghamton	5	1, 681	47	3	. 14
Boulder	129	331	438	132	6. 94
Carnegie	−2	667	150	22	1. 04
Chattanooga	15	4, 493	1, 843	41	1. 94
Dallas	122	944	6, 395	677	32. 23
Denver	65	2, 725	665	28	1. 33
Los Angeles: Pico-Rivera		1, 484	12, 199	822	39. 14
Lowell	6	1, 795	130	7	. 36
Portland	34	2, 107	90	4	. 22
Streator	20	27	7	27	1. 28
Wabash	33	283	34	12	. 57
Waterbury	11	1, 067	145	13	. 61
Wheeling	−5	6, 532	111	2	. 08

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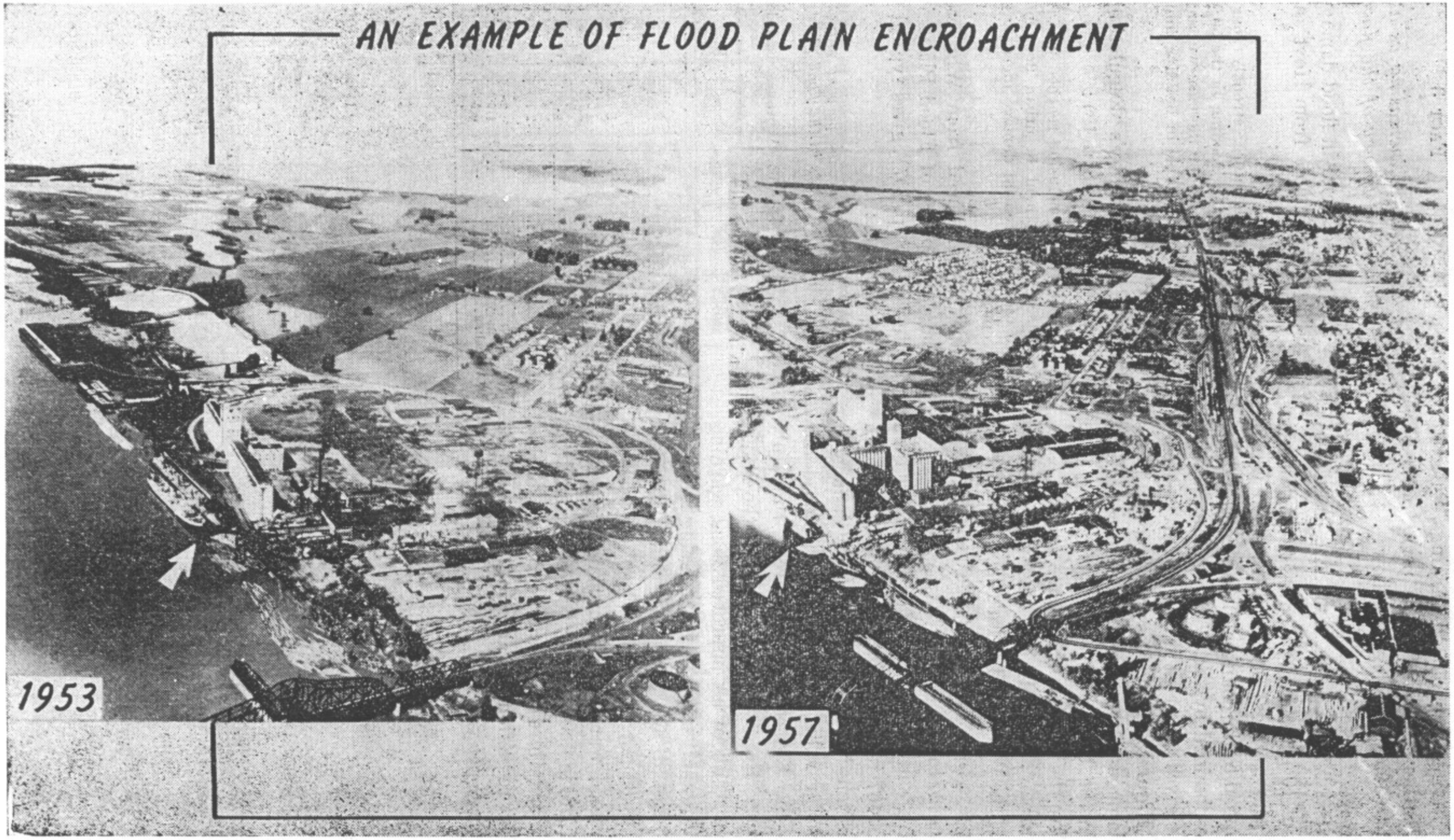
FIGURE 4



One of the many possible photographic illustrations of the change is shown in figure 4.

In his summary of the December 1958 National Conference on Flood Plain Regulation and Insurance ("State Government," spring 1959, published by the Council of State Governments), Gilbert F. White wrote:

Perhaps the basic factor recognized at the conference is that, although there have been remarkable engineering achievements over the period of 22 years since the first national Flood Control Act passed, flood damage continued to mount. The occupance of flood plains has continued to spread. Whether such increase in damage potential is greater than the decrease in damages resulting from engineering works is problematical. The important point is that the total volume of damage has not decreased * * *. Those who know the facts no longer see the problem as one to be solved by engineering alone, or by engineering in combination with upstream land management. They see it as engineering plus community planning in the broad sense. The measures for damage reduction may include changes in buildings, *improved flood forecasting*, zoning regulations * * *. [Italic ours.]

Fact 4

Flood forecasting is a means of flood control

Since both flood forecasting and flood control are means of reducing flood damages, it follows, to quote the report of the President's Water Resources Policy Commission, volume I, "A Water policy for the American People" (1950, p. 146), that:

Flood forecasting should be considered as an integral part of any system whose function is to prevent or reduce the extent of damage caused by floods. It accomplishes its purpose by creating the opportunity for preparation * * *. In the early 1930's when the modern flood control program was in its early stages, the Army Engineers submitted to Congress a wide range of flood control possibilities supported by substantial benefit-cost ratios. But, as the program has gone forward, the proportion of projects with relatively low benefit-cost ratios has increased. In fact, there are flood situations in which the flood control possibilities involve costs which exceed benefits. It is in connection with the latter situations, especially, that consideration should be given to increasing the effectiveness of flood forecasting.

Bureau of the Budget Circular A-47 recommended that—

any program or project concerned with flood control * * * shall give consideration * * * to all methods of preventing or reducing flood damage—

including "flood forecasting."

The Comprehensive Survey of the New England-New York Inter-Agency Committee (1955, pt. I, p. III-22) said:

In areas where no flood protection works are contemplated, or where only partial protection is provided, a reduction of flood damages may be obtained at relatively low cost by providing flood forecasting and warning services coupled with local plans for evacuation and protection measures to be taken on the basis of forecasts and warnings. In areas where the time interval between the onset of rainfall and ensuing flood is very short, a local representative may be trained in the procedures for issuing warnings based on a special river and rainfall network reporting to him. The cost of this measure has not been estimated, but for individual communities it should be quite small.

Fact 5

Flood forecasts guide flood management

Flood control works, particularly when involved with reservoir storage serving multiple-purpose objectives, require complex management for the most effective operation.

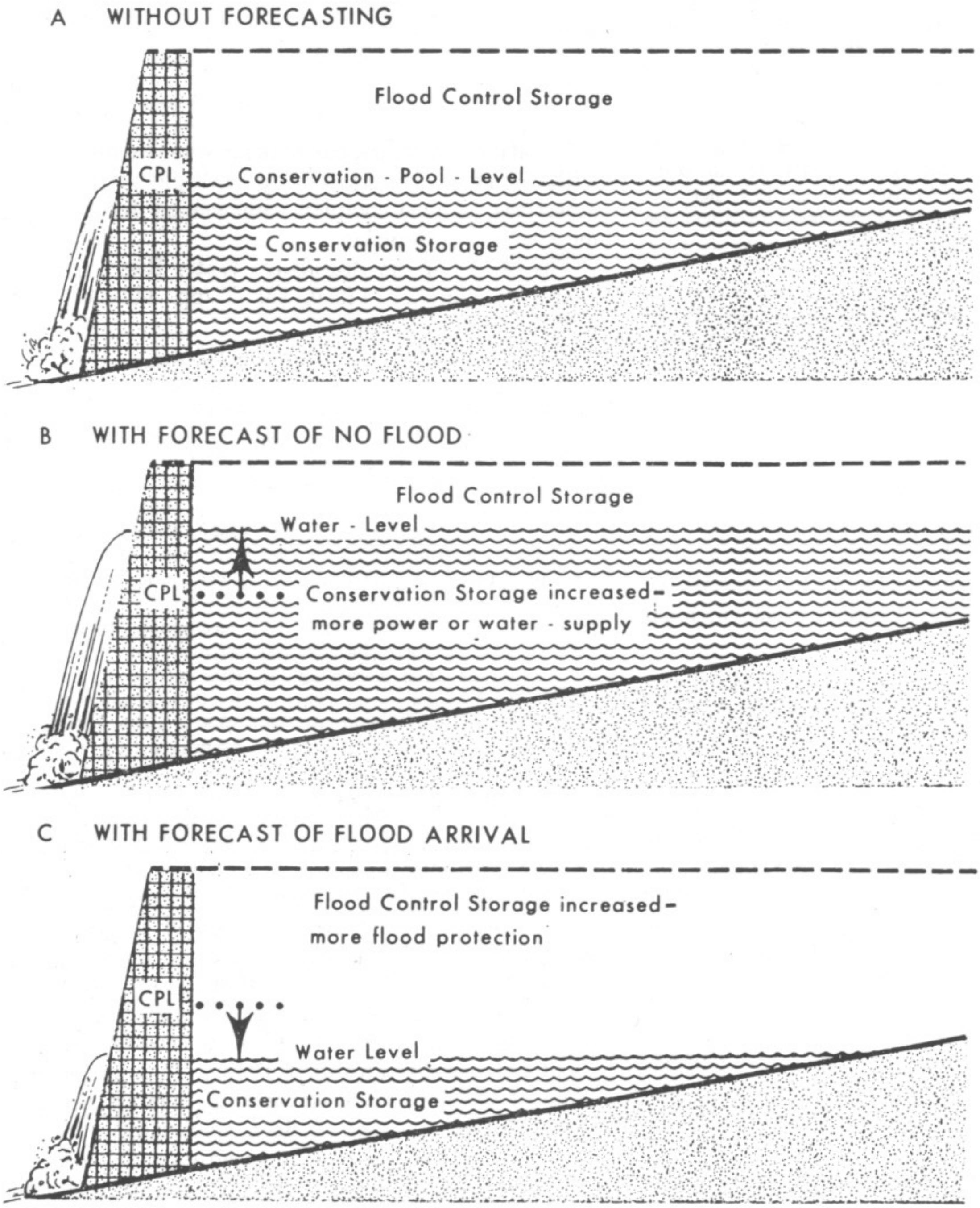
The report of the President's Water Resources Policy Commission (1950, vol. I, pp. 146–147) said:

Without forecasting there must be a reasonably rigid separation of the part of the reservoir capacity reserved for flood control and the part utilized for conservation storage, for generation of power, maintenance of streamflow, and other purposes. Under such circumstances, the part of the reservoir reserved for flood control represents the limit of the projects' contribution to that purpose and must be emptied as rapidly as possible after a flood has passed in preparation for the next flood. If effective flood forecasting is available, however, the use of the reservoir capacity can be placed on a truly multiple-purpose basis. In other words, to a measurable extent, each purpose can have the advantage of a portion of the other's storage, thus increasing the potentialities of the project for both purposes. This means that, pending a flood warning, the reservoirs can be held at a higher level for power or other purposes in the assurance that the warning will come far enough in advance to permit the emptying of the reservoir in time to catch the advancing flood. Similarly, the drawdown in anticipation of the flood can encroach upon the capacity reserved for power or other purposes thus augmenting the protection which the project offers to the lower valley.

A schematic example of this type of management is shown in figure 5. As another example, Rutter (Transactions ASCE, 1951, p. 671) has shown that during three floods in the Tennessee River the effectiveness of TVA reservoirs was about half of the theoretical limit. That is, because of the need to reserve storage against the possibility of a subsequent flood, uncertainties in the magnitude of the flood in progress and other factors, each acre-foot of reservoir capacity produced only about one-half as much flood reduction as it might have if the TVA had been able to operate perfectly. To put it another way, twice as much storage space is required for flood reduction than would be required if we had perfect knowledge of future streamflow.

FIGURE 5

OPERATION OF MULTI-PURPOSE DAM



CPL = CONSERVATION POOL LEVEL

An estimate of the total storage capacity in Corps of Engineers' reservoirs subject to operation—that is, with gates which can be controlled on the basis of forecasts—is 160 million acre-feet. A 10 percent gain in operational effectiveness through an improved forecasting service would represent 16 million acre-feet of storage space converted to more effective use.

On the other side of the picture, there are millions of acre-feet of storage space in thousands of small and medium-sized reservoirs used solely for conservation. The reservoirs are filled at the earliest possible minute without any reservation of space for flood control. With reliable river forecasts it would be entirely possible to achieve a substantial amount of flood control value from these reservoirs with no less water conservation.

Fact 6

Water management and conservation depend on forecasts of streamflow

Operation of reservoirs and other structures in the event or anticipation of floods is only part of water management. The operators of powerplants, irrigation works, and water supply systems have daily decisions to make even in the absence of flood. They have to decide when gates are to be opened or closed and by how much, and which reservoirs are to be drawn upon. Load must be shifted between the water power and the steam power plants of a system so as to use each to best advantage. Drafts on storage can only be made with due regard to contents on hand and in prospect.

Quoting from Hoyt and Langbein's "Water Facts for the Nation's Future" (1959, p. 217), from which much of the above is paraphrased:

> At the beginning of the year, the operator watches the snow cover over the mountain watersheds tributary to his reservoir and, as winter comes, he makes his calculations of how much runoff the snow cover will produce in the spring thaw * * *. He then figures his chances of filling the reservoir. If his computations indicate that one reservoir will spill, while the second appears to lack sufficient inflow to fill, he may order that all power drafts be made on the first and close the gates of the second. By transferring the demand, he can in a way transfer water from the first to the second reservoir and thereby increase his chances of filling both reservoirs * * *. His problem is to meet power commitments, the summer's irrigation demand of the water user, and, not to be overlooked, the exactions of a court decree about minimum flows at various irrigation headworks.

Information for an operation as described above is provided by the Weather Bureau's water-supply forecasts in which accumulated precipitation at regular climatological stations of the Bureau is used as an index to future runoff from the snowpack. Recent experimental use of high-speed digital computers has demonstrated the possibility of preparing such forecasts in a period of only about 45 minutes for a river basin the size of the Columbia River. It opens the opportunity for more detailed and more frequent forecasts, closely coordinated with the latest weather observations and forecasts. By manual means, the forecasts required as many as 5 man-days.

Issued as much as 6 months in advance, these long-range forecasts not only permit the reservoir operator to effectively control the storage allocations and draft on his various reservoirs, but also serve many other uses.

The hydroelectric power producer will determine from such forecasts his probable need for thermal generation. In low-flow years he will carry baseload or part of the baseload with thermal generation and use hydroelectric power for its most effective purpose—which is peakload. In years of abundant water, he may use streamflow in excess of storage capacity to carry baseload and use thermal power for peaking.

The farmer, with advance knowledge of the probable water supply for the following summer, can select crops and acreages compatible with the water he expects to be available. He need not plant large acreages of land which he later finds he cannot irrigate; and in wet years he is forewarned that he can plant a larger than normal acreage and use water for beneficial irrigation that might otherwise go to waste.

The water supply operator who is dependent on a combination of ground water and surface water for his water supply, will use such forecasts to determine how much surface water he can use and regulate his ground water pumping accordingly. In many areas of ground-water overdraft, a substantial conservation of ground water may be effected in this way. Certainly, there is no point in withdrawing ground water at a heavy rate only to find later that there is excess surface water which must be wasted because of lack of storage facilities.

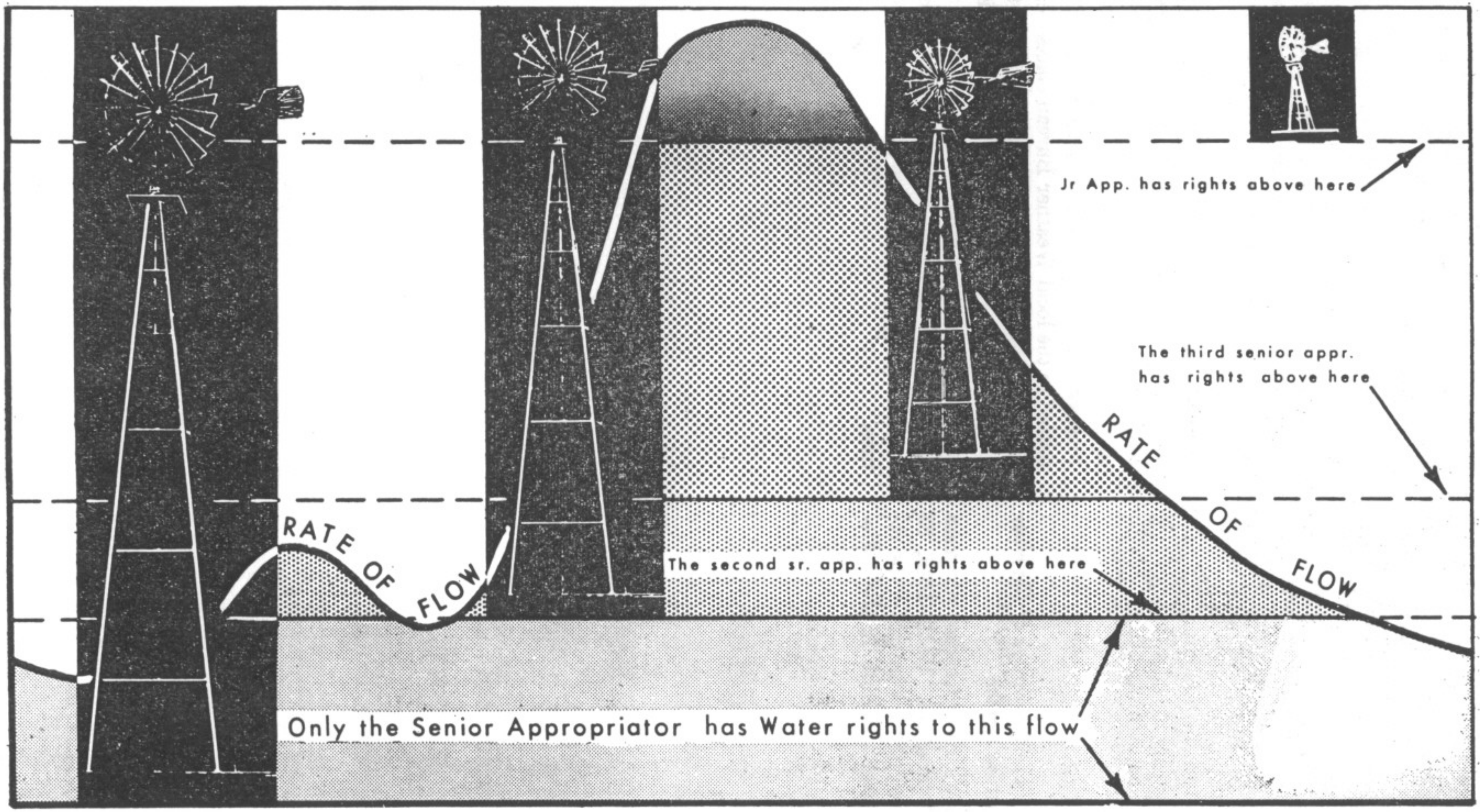
Short-range operational forecasts extending from 1 to 10 days in advance offer many possible aids to effective utilization of water. One example is in the exercise of water rights. Western water rights practice often assigns only to the senior appropriator on a stream the initial few cubic-feet-per-second of flow, the next senior appropriator being allowed access only to flow in excess of the initial rate, and so on for the less senior appropriators, until the junior appropriator has access only to flow exceeding a high and infrequent rate. (See fig. 6.) The senior appropriator has no problem, for he knows that he can always divert flow when he needs it, but the junior appropriators must be prepared to use water when it is available. The junior appropriator must have his crops planted, his distribution system ready to accept water, and someone on hand to operate the headgate during the periods when the flow is near his limiting value. With forecasts giving a few hours to a few days warning, he can be better prepared and ready to use water which might otherwise go to waste because of unpreparedness.

A somewhat similar problem is that of the irrigator who just closes his headgate and terminates the period of irrigation as natural rainfall begins. If he had had adequate forecasts of the rainfall he might have delayed his irrigation, using the rainfall as a substitute and conserving water in the reservoir for later use. He cannot, however, forego the use of irrigation water at those times when required to keep his crop in top shape unless the rainfall forecasts are highly accurate as to amount and time. Thus, the quantitative precipitation forecasting techniques, which could be so useful in flood forecasting, have an equal value in water conservation.

FIGURE 6

WATER RIGHTS

TO EXERCISE THESE WATER RIGHTS THE APPROPRIATORS NEED STREAM FLOW FORECASTS



Brief mention should be made of some other benefits from river forecasting. The forecasts can aid the contractor constructing dams, bridges, or other works in or near a river channel, speeding the work and preventing lost time and money by permitting him to schedule his work most effectively. They aid the commercial river navigator by allowing him to schedule his loading and hence the draft of his vessel within the depth expected during the course of his trip. They permit readjustment of municipal and industrial waste discharges in order that pollution of streams be maintained within set standards during periods of low flow.

Need 1

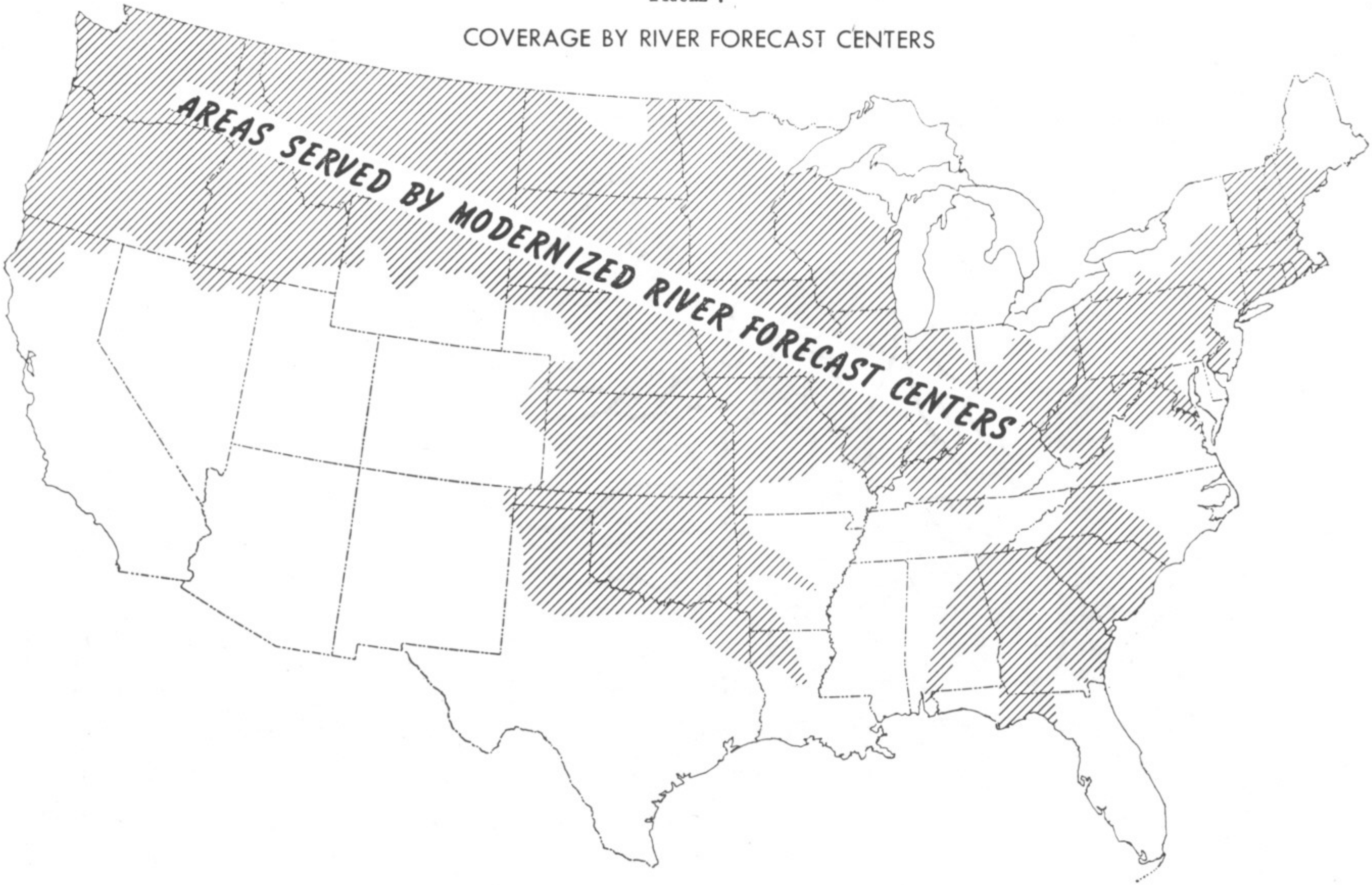
Complete modernization and coverage of the river forecasting service

The Weather Bureau's river forecast program is necessarily a field program. Until 1945, 85 regular Weather Bureau offices were given the responsibility for the river program in their districts. This was added to their other responsibilities—for observations, general public service, aviation service, etc. Since floods are only occasional events in any one district, the river services tended to suffer at the expense of the other station activities for which there are more frequent and routine demands. Even during floods, there was inevitable competition from peak demands for the other services provided by the station.

In 1946, a beginning was made in the establishment of river forecast centers, staffed by trained hydrologists and devoted entirely to river forecasting and the development and refinement of forecast procedures. The forecasts are transmitted to the local Weather Bureau offices—called river district offices—for dissemination in their districts. The results have been excellent. Forecast procedures have been modernized. The forecasts are more accurate, are made further in advance, and are made for more points and for more uses.

FIGURE 7

COVERAGE BY RIVER FORECAST CENTERS



UNSHADED AREAS DO NOT RECEIVE RIVER FORECAST CENTER SERVICE

FIGURE 8

RIVER DISTRICT OFFICES IN THE RIVER AND FLOOD FORECAST SERVICE

UNSHADED AREAS SHOW DISTRICTS WITHOUT A FULL-TIME RIVER MAN

The existing river forecast center coverage is shown in figure 7. A large portion of the country is thus seen to be still without such coverage. Extension to the entire country, including Alaska, Hawaii, and Puerto Rico, should be included in national water resources planning.

In the areas served by river forecast centers, the river district offices function to disseminate warnings, collect reports from observers, and keep the forecast center informed of the needs of the area. Where no river forecast center exists, the river district office must also assume the forecasting function. Note (fig. 8) that some areas of the contiguous United States have no service whatsoever even at this level, which is also true of Alaska, Hawaii, and Puerto Rico. However, an even greater inadequacy is shown in the number of river district offices that have not even one full-time employee to serve the needs of the river district.

No forecasts or warnings can be issued without knowledge of what has happened and what is happening. This information is reported by networks of stations observing rainfall, river stage, snow cover and other elements daily or more frequently. In many cases river observations are hazardous during high water. In some key areas there may be no inhabitants to make observations. Landline communications may fail in storm or flood. Beside an adequate density of observer reporting stations, it is thus necessary to have unmanned automatic stations reporting continuously, periodically or on call by radio or radar means. Although some advances in telemetering of information have been made, it is still true, as said by Hoyt and Langbein in "Water Facts for the Nation's Future" (1959, p. 154) that:

> The Weather Bureau's use of radio telemetering of rainfall or river stages to improve its nationwide flood-forecasting service will depend on larger appropriations for its forecasting services to enable it to afford it.

Basic to the support of a modernized river forecasting service is continued research in techniques for forecasting. Hydrology is a relatively new science in which there is a rapid development. Especially for a forecast and warning service, there should in addition be a development of electronic equipment to improve the accuracy and accelerate the transmission of observations and the dissemination of warnings, as well as the adaptation of the forecast procedure to high-speed computers. It is not sufficient to stand pat on existing techniques so long as there are prospects of increased accuracy or longer warning time.

NEED 2

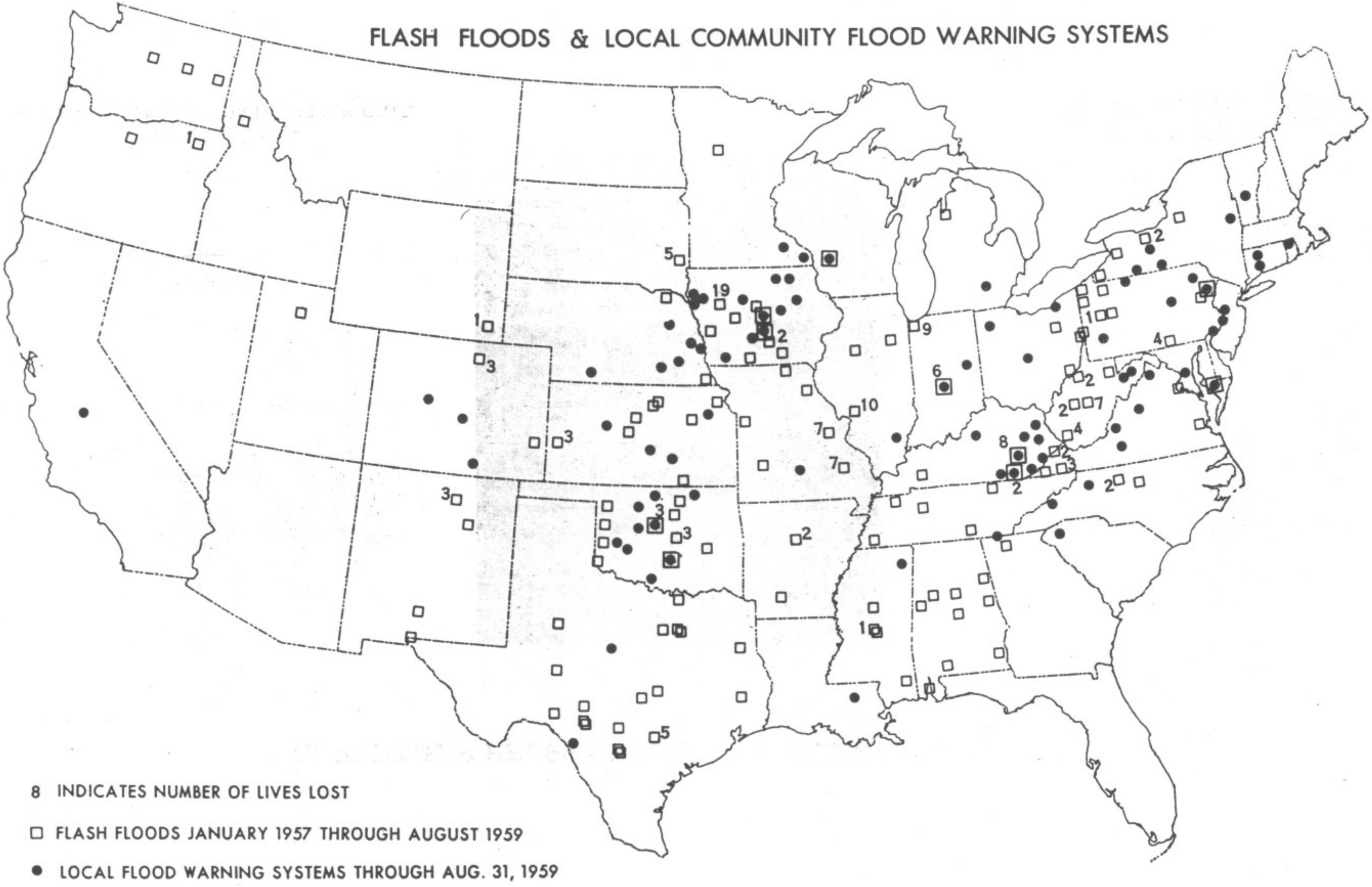
Self-help flash flood warning systems

On small streams, it is often impossible to collect the necessary observations, transmit them to an appropriate office, process them, prepare a forecast and relay the forecast to the community which is threatened by flood in time to do any good. A flood peak may occur within a matter of minutes or a very few hours after the occurrence of heavy rainfall. In a number of instances, the Weather Bureau has established cooperative flash-flood warning systems. The Bureau assists the community in establishing a network of rainfall and river observing stations and a local flood warning representative is appointed to collect the reports and to issue the forecast on the basis of a procedure furnished to him by the Bureau. When possible, the Bureau provides him with advance warning of rainfall and soil moisture conditions favoring flood.

The advent of radar (which "sees" rainfall over a large area) makes possible a more active and more satisfactory program. The plan, where radar exists, is to tie the flash-flood areas to the radar station. The warning networks, with a flood-warning representative, will be established as before, but the radar station will now be able to alert the flood-warning representative to imminent heavy rains, and to counsel him on the distribution of the rain over his basin and also its indicated duration. All this can be contributed from radar watch of the rain echoes on the radarscope. With at least several alerts of this type a year, the local warning network should remain operative. A pilot project, staffed for this type of operation, has been successful at Des Moines, with about 10 flash-flood areas now being served. What the plan requires is a radar flash-flood specialist at the radar station, repeated liaison with the areas served, a high density of inexpensive oncall rain gages to calibrate the radar echoes for intensity of rainfall, and assistance from a river forecast center in developing the quick forecast procedures required by the local flood warning representative. Every radar station can be the guiding center of a group of flash-flood warning systems. Implementation of such a program would be the first effective attack on the flash-flood warning problem.

The magnitude of the problem is indicated in figure 9, showing both the locations of the present warning networks and the occurrences of flash floods (i.e., those reported). The 87 existing systems, it can be seen, provided warnings for only 10 of the 125 occurrences (or 8 percent) indicating that the warning systems should be increased to about 12 times the present number, or to about 1,000. In many of the floods not warned of, a warning of a few minutes could have saved lives, a few hours would make possible considerable saving of property. And the annual cost of a flash-flood warning system for a community is less than the cost of a secondhand automobile that could be saved by a warning.

Figure 9


FLASH FLOODS & LOCAL COMMUNITY FLOOD WARNING SYSTEMS
8 INDICATES NUMBER OF LIVES LOST
□ FLASH FLOODS JANUARY 1957 THROUGH AUGUST 1959
● LOCAL FLOOD WARNING SYSTEMS THROUGH AUG. 31, 1959

HOW RADAR HELPS DEFINE THE RAINFALL PATTERN

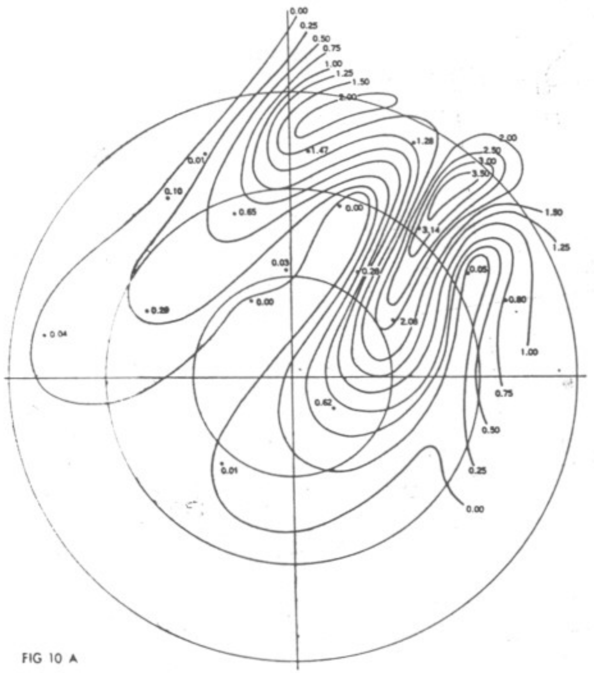


FIG 10 A

RAINFALL MAP
USING OBSERVED PRECIPITATION ONLY

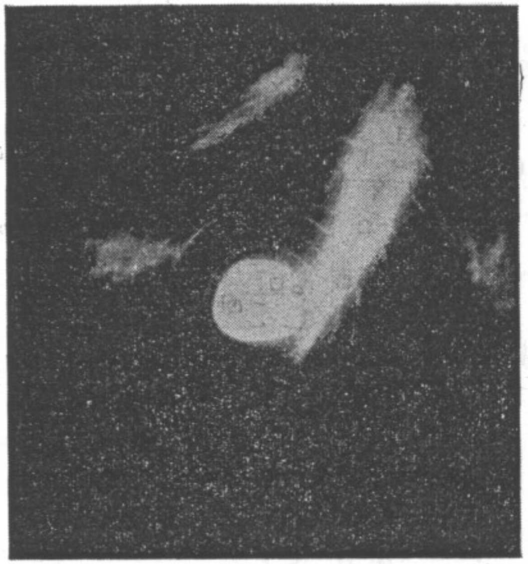
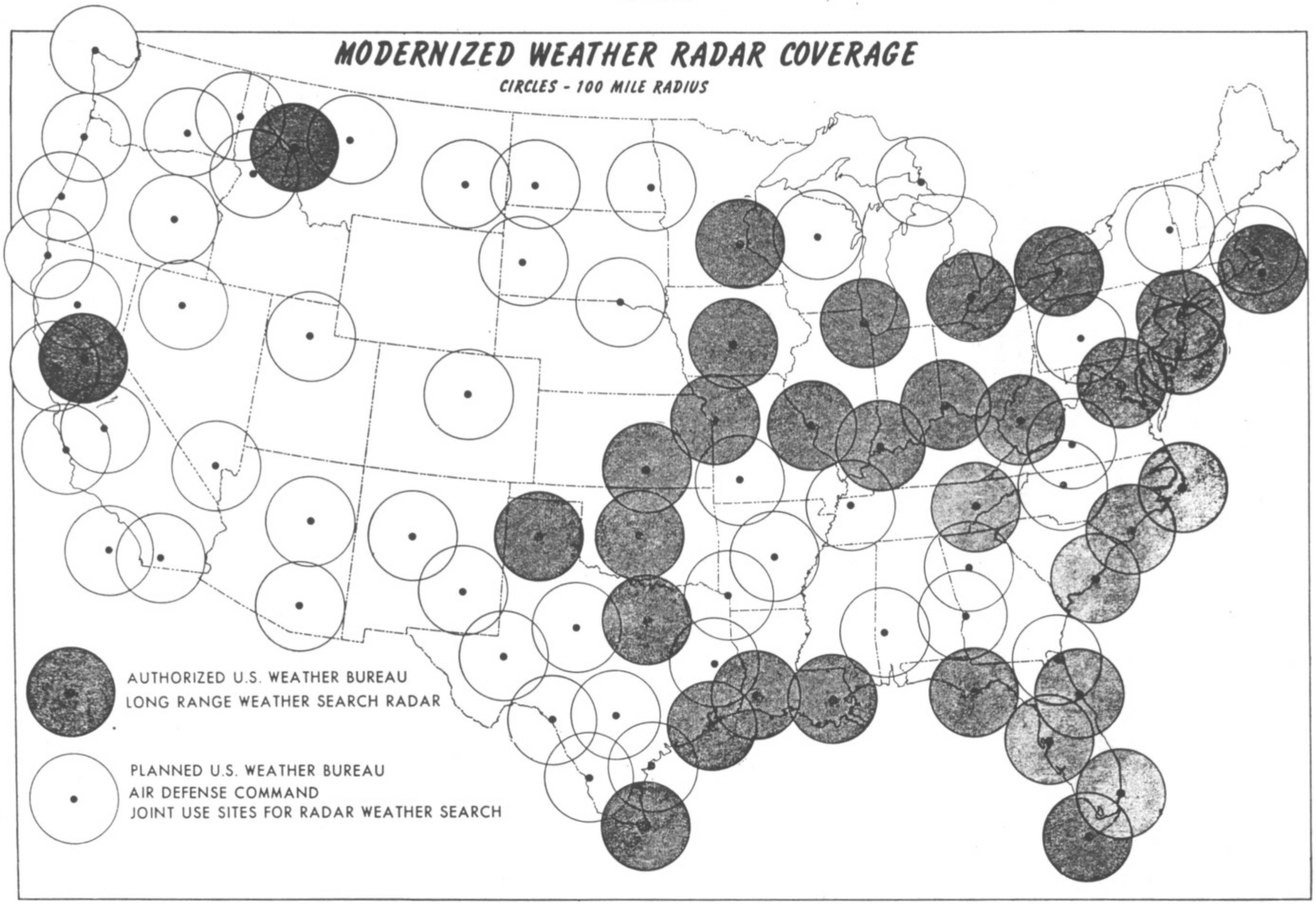


FIG 10 B SIX - HOUR MULTIPLE EXPOSURE
RADAR ECHO INTEGRATION

FIG 10 C

RAINFALL MAP
USING INTEGRATED RADAR ECHOES
WITH OBSERVED PRECIPITATION

Figure 11


MODERNIZED WEATHER RADAR COVERAGE
CIRCLES - 100 MILE RADIUS
AUTHORIZED U.S. WEATHER BUREAU
LONG RANGE WEATHER SEARCH RADAR
PLANNED U.S. WEATHER BUREAU
AIR DEFENSE COMMAND
JOINT USE SITES FOR RADAR WEATHER SEARCH

Need 3

Complete weather-radar coverage

While there is no accurate substitute for the rain gage now, and a greater density of gages is still required, the advent of radar is now of great assistance in estimating intensity of rainfall where not measured, and in helping define the areal distribution (which is required for the volumetric determination required in river forecasting). The way in which radar can help now is illustrated in figure 10.

In addition, it detects localized areas of heavy rainfall, of hail, and even tornadoes, and makes possible the observation of their paths and duration for warning of all communities in danger.

Further development is required in the integration of the radar images through time, to obtain rainfall amounts over area for a number of hours, and for fast transmission of this integrated picture to weather and river forecasters and to water management. It is certainly possible that such development of radar will reduce the required raingaging network to just a network of key gages to be related to the radar observation. The Weather Bureau has developed and begun the installation of rain gages that are read by radar.

Current and planned coverage of the country by modernized weather radar is shown in figure 11.

Need 4

Quantitative forecasting of precipitation

The greatest advance in river forecasting in recent years has been the use of precipitation data. Twenty-five years ago most flood forecasts were based on reported upstream river stages. Forecasts were not possible for small basins and could only be issued after the flood had begun to crest in the headwaters of large basins. Now relations have been devised by which it is possible to estimate the amount of runoff from a given rainstorm and the peak stage which this runoff will cause. This permits warnings on small streams, and these can be released much earlier than if it were necessary to wait for river stage data.

If a river forecast can be based on observed rainfall, it also can be based on accurate forecasts of amount of rainfall. The river forecast could be extended as far in advance as the rainfall forecast. Quantitative precipitation forecasts would increase warning time for all the protective measures that should be taken in advance of the flood. They would provide the facts for operation that the management of flood control and other water-use enterprises require. They would also be a boon to the irrigator, who would not only save the irrigation water he might otherwise use, but would save his crop and land from the deleterious effects of overwatering.

A number of promising approaches to the problem of quantitative precipitation forecasting are known and the importance of the problem justifies a substantial research effort. The success in the similar problem of tornado forecasting—about which serious doubts were raised not too many years ago—is adequate answer to honest doubts that exist in this field. A concentration of effort is called for similar to what is being done in tornado and hurricane forecasting.

Need 5

Systematic collection of flood damage and flood risk data

The Weather Bureau has been collecting and tabulating flood damage figures year by year and river by river since 1903. It relies largely on questionnaires distributed by field officials after each flood to county and city engineers and other responsible respondents. The returns are coordinated and checked with other agencies, such as the Corps of Engineers. They are the only data of this type regularly published and have the merit of continuity, national coverage, and consistency in manner of collection. They have been widely used as an index. However, the Bureau must admit their deficiency in coverage of agricultural damages, indirect losses, and headwater and isolated flash-flood areas. The situation is exemplified in a quotation from Hoyt and Langbein's "Water Facts for the Nation's Future" (1959, p. 75):

> Assuming the Corps of Engineers' "downstream" estimate and the Department of Agriculture's "upstream" estimate are mutually exclusive, in part, we may conclude that the average annual flood damages in the United States exceed a billion dollars. This is about four times as large as the Weather Bureau estimate based on its surveys.

Factual data on flood damages and flood risks are essential to all flood control planning. The need for a systematic, possibly interagency effort in the collection of flood damage data seems obvious.

In connection with flood-plain zoning and flood insurance, maps of the flood risk in each community are needed. The best would show, practically street by street, the chances of floods of particular magnitudes. An outline of the possibilities in such maps or reports is contained in Murphy's "Regulating Flood-Plain Development," p. 149–153.

Fact 7

Improved flood forecasting can double the savings in flood damages at continued high benefit-cost ratio

The Weather Bureau now makes flood forecasts for about 1,600 points, mostly on the principal streams and their main tributaries. The University of Chicago's "Changes in Urban Occupance of Flood Plains" (p. 36) estimates 1,020 cities with flood problems. The text suggests that about 200 more localities below 9,500 population should be added to this total and "as a general rule, each urban area may be regarded as having two or more flood plains." The number of potential forecast points is thus about 3,000, and growing with continued urban expansion. The upward trend in flood damages has already been noted.

How much more could be saved by an improved flood forecasting service? Such an estimate is suggested by the comprehensive report of the Arkansas-White-Red Basins Inter-Agency Committee (1955). Their comprehensive flood damage estimates (pt. I, p. 27) are over four times as great as the Weather Bureau's—

* * * of which (pt. II, sec. 2, vol. A, p. 174) an estimated 5 percent is to movable property which can be saved on the basis of flood warnings issued sufficiently in advance of each flood. Benefits to the operation of the flood control projects resulting from the forecasting service have not been evaluated.

On a national basis, this gives a potential national flood damage saving by improved forecasts of $67,500,000, or more than double the present saving of over $30 million. The cost of the Weather Bureau's flood forecasting service, which produces this saving, is less than $1,500,000; a perfected service would cost two to three times as much—with benefit-to-cost ratio of 15 or 20 to 1. In addition, the loss of life in floods, reduced from 100 to 80 during the past 10 years, could probably be further reduced by about 90 percent.

There is no similar estimate of the benefits of an improved river and flood forecasting service to operation and management of water control, water conservation, and water use projects. However, some measure of magnitude may be obtained by considering the annual value of all harvested crops. In 1954 ("Statistical Abstract of the United States," 1958, p. 651), it was about $19 billion. Only a 1 percent increase would represent an economic gain of $190 million. The added cost to the Weather Bureau's improved flood forecast and warning service would be 10 to 20 percent, or less than $1 million.

II. HYDROMETEOROLOGICAL DATA FOR PLANNING

FACT 8

The primary source and archives for the Nation's hydrometeorological data is the Weather Bureau

By its organic legislation (15 U.S.C. 313) the Weather Bureau is charged with—

> * * * the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to record the climatic conditions of the United States.

In addition, the 83d Congress, by amendment of the 1938 Flood Control Act (33 U.S.C. 706):

> * * * authorized an expenditure as required, from any appropriations heretofore or hereafter made for flood control, rivers and harbors, and related purposes by the United States, for the establishment, operation and maintenance by the Weather Bureau of a network of recording and nonrecording precipitation stations, known as the Hydroclimatic Network, whenever in the opinion of the Chief of Engineers and the Chief of the Weather Bureau such service is advisable in connection with either preliminary examinations and surveys or works of improvement authoirzed by the law for flood control, rivers and harbors, and related purposes, and the Secretary of the Army upon the recommendation of the Chief of Engineers is authorized to allot the Weather Bureau funds for said expenditure.

Similar types of observations are taken for and by other agencies such as the Bureau of Reclamation, Soil Conservation Service, etc.

Reports and observations for the above, and for the Bureau's weather and river forecasting programs, provide the basic hydrometeorological data to be summarized, analyzed, and interpreted for water resources planning purposes. These are more than merely precipitation and evaporation data. R. K. Linsley in his "Techniques for Surveying Surface Water Resources" (WMO technical note No. 26, 1958, p. 29) lists the following as elements to be observed at hydrometeorological stations:

> Short-wave radiation, bright sunshine, cloudiness, net radiation, soil temperature, air temperature, precipitation, snowfall depth, snow cover depth and water equivalent, precipitation intensity, *dewfall*, humidity, weather, *potential and actual evapotranspiration*, pan evaporation including pan water temperature, soil moisture, barometric pressure, surface wind.

All but the italicized elements are observed at Weather Bureau stations, the dashed underlining indicating extremely few observations of that element. In published form the tabulations and summaries of these observations include also the observations of cooperating agencies. Three regional weather records processing centers place the data on punchcards which are machine processed for publication and subjected or made available for high-speed electronic analysis for various purposes. The Bureau's National Weather Records Center at Asheville also processes data and acts as the national repository for all data made available to it.

From these data—organized, analyzed, and interpreted—come the answers to the planner's questions: How much rain (or snow) fell in this storm and how was it distributed in time and in area? How often does this intensity occur? What is the minimum we can have (over a period) and what the maximum? What is the maximum of record and how much more than that is possible—in a given time, in a given season, over a given area? These questions can apply to various of the elements observed—wind, temperature, humidity, and solar radiation, for example, are all important in the problems of evaporation or snowmelt.

FACT 9

Precipitation is the basic source of water supply

The primary source of the water vapor for precipitation is the sea. The process is a worldwide desalting process taking place in a tremendous solar still whose absorption area is the entire surface of the oceans and whose heat source is the sun. The water so evaporated and then condensed by cooling as it rises to lower pressures in the atmosphere results in an average of 30 inches of precipitation per year over the United States—4,900 million acre-feet. But the variation of this average annual rainfall is from about 5 inches in the arid southwest to 200 inches in the mountainous northwest. At some points in the United States it has rained over 35 inches in 1 day, over 12 inches in 1 hour, and over 1 inch in 1 minute. And then again, it may not rain for weeks or months. It is obvious we need to know a lot more than averages for planning, for all these are variations in our basic water supply.

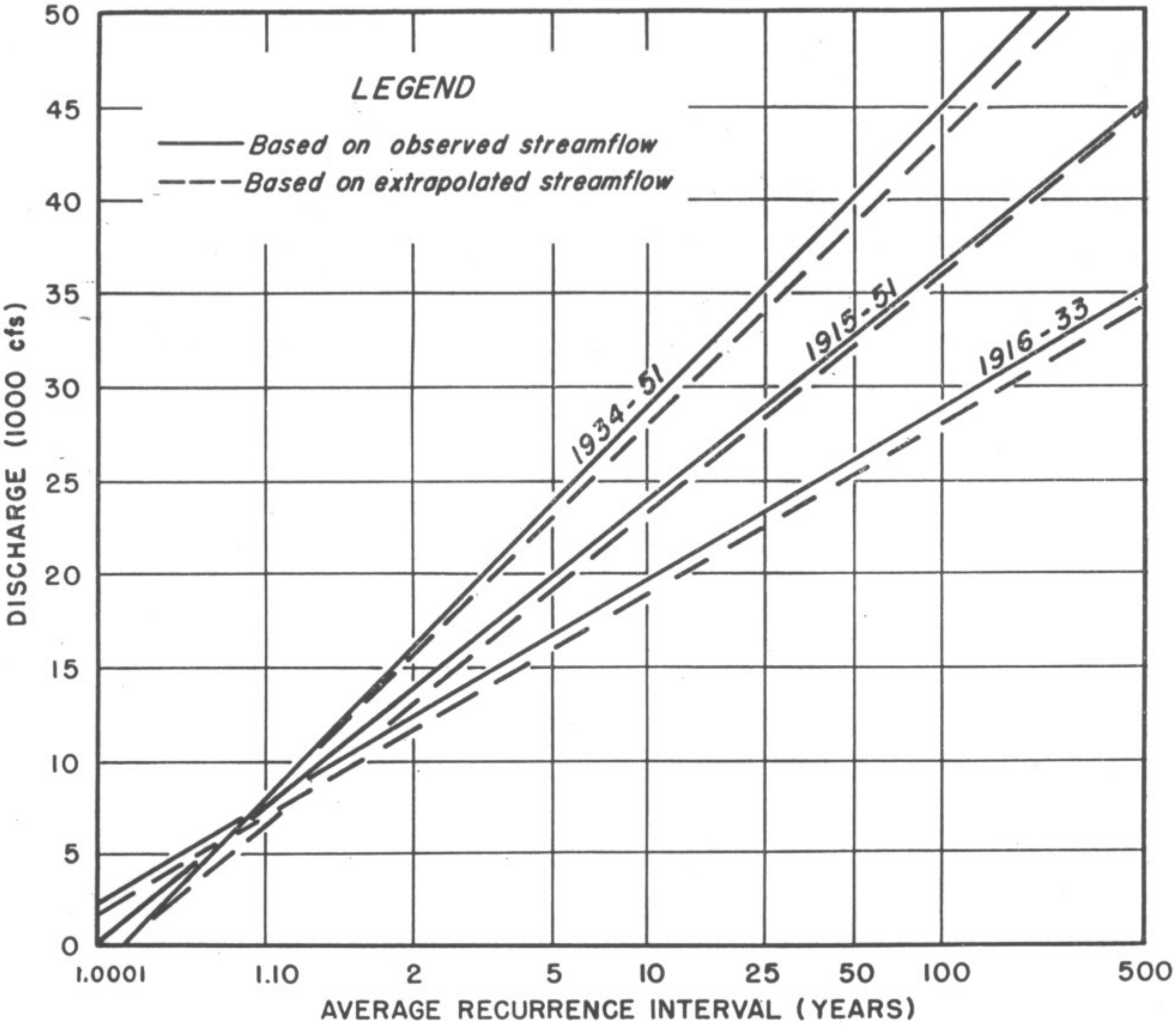
More than averages are and can be made available. Analysis of the past record can tell the farmer his climatic risk, his chances for success with and without irrigation, and how much irrigation. Both overdesign and underdesign of drainage facilities for airports, highways and buildings can be prevented by frequency analyses of rainfall data that provide information on how great an intensity can be expected once in 50, 25, 10 or any other number of years. Conservation and protection reservoirs can be designed for their proper capacities on the basis of these studies. Much material of this type has been provided the Soil Conservation Service for guidance in planning its small watershed protection program.

Since 1939 the Weather Bureau has been preparing estimates of probable maximum precipitation for the Corps of Engineers, which uses them as a factor in spillway design. While it does not follow that all reservoirs should be designed for the probable maximum flood, the designer should have knowledge of the risk involved in designing for less. Too small a spillway exposes the downstream area to risk of dam failure. Too large a spillway means added cost and, in some cases, less reservoir capacity for useful storage.

The techniques used in flood forecasting can also be used to estimate the magnitude of past floods as far as adequate rainfall records are available. What is required is a simultaneous rainfall and streamflow record for, say, 10 years or long enough to establish rainfall-runoff relations that can then be extrapolated into the past. Since rainfall records are generally of greater length than streamflow records, this extrapolation increases the effective length of record for flood-frequency analysis. Figure 12 shows a comparison between frequency curves based on the extrapolated record and on the observed record. Here, then, is another way toward improved design of structures from the viewpoint of both safety and water conservation.

The technique has further possibilities. By developing the rainfall-runoff relation from the data available prior to control, regulation or other modification of natural streamflow, the technique can be used to test the effectiveness of the controls or modifications. It can estimate what would have happened without the controls, which can be compared with what happened with controls. It is, in fact, a technique necessary to evaluation of all types of measures affecting streamflow, upstream and downstream—if an earlier record is available. It is also the technique, for example, if proper preparation is made by advance installation of rain gage and stream gage networks, to study the effects of urbanization on streamflow.

FIGURE 12



Comparison streamflow frequency curves for the Hocking River, Athens, Ohio

Even the most common of the values available—the average rainfall, especially over an area—can be made significantly more accurate. All that any network of gages can do is to sample the rainfall. And if the rainfall over the area sampled is extremely variable, as it is in mountainous country, the sampling can often be inadequate—and made more so by the practical necessity to locate gages where we can find observers, i.e., in inhabited areas. The way to greater accuracy is to discover the relationship between gage catch and gage location—the elevation of the station, the slope and aspect of the ground surface in the vicinity, the distance from effective barriers to storms and to sources of storm moisture, etc. Figure 13 compares rainfall maps for western Colorado. One shows the rainfall pattern based on the available network, the other shows it after topographic adjustment as described above. The contrast is not only startling in detail but in gross values. The area with over 30 inches of rain is about doubled, the total yield from precipitation is seen to be 6 million acre-feet greater than was previously known.

Need 6

More precipitation data and analysis

The synthetic techniques described, and others, make the greatest possible use of available data. They need to be continued because observations without analysis to fill in the gaps are clearly inadequate. However, the comparative success of these techniques does not eliminate the need for judicious network expansion. To increase accuracy of our knowledge, a more extensive observation of the facts is required. Nevertheless, even with a considerable expansion of observational networks, it would be many years before there would be a sufficient accumulation of data to be of real value in planning. Until then, synthetic techniques will be of great value. Furthermore, in planning network expansion, the analytic, synthetic, and interpretive techniques will provide the guide to efficient location of new stations.

FIGURE 13

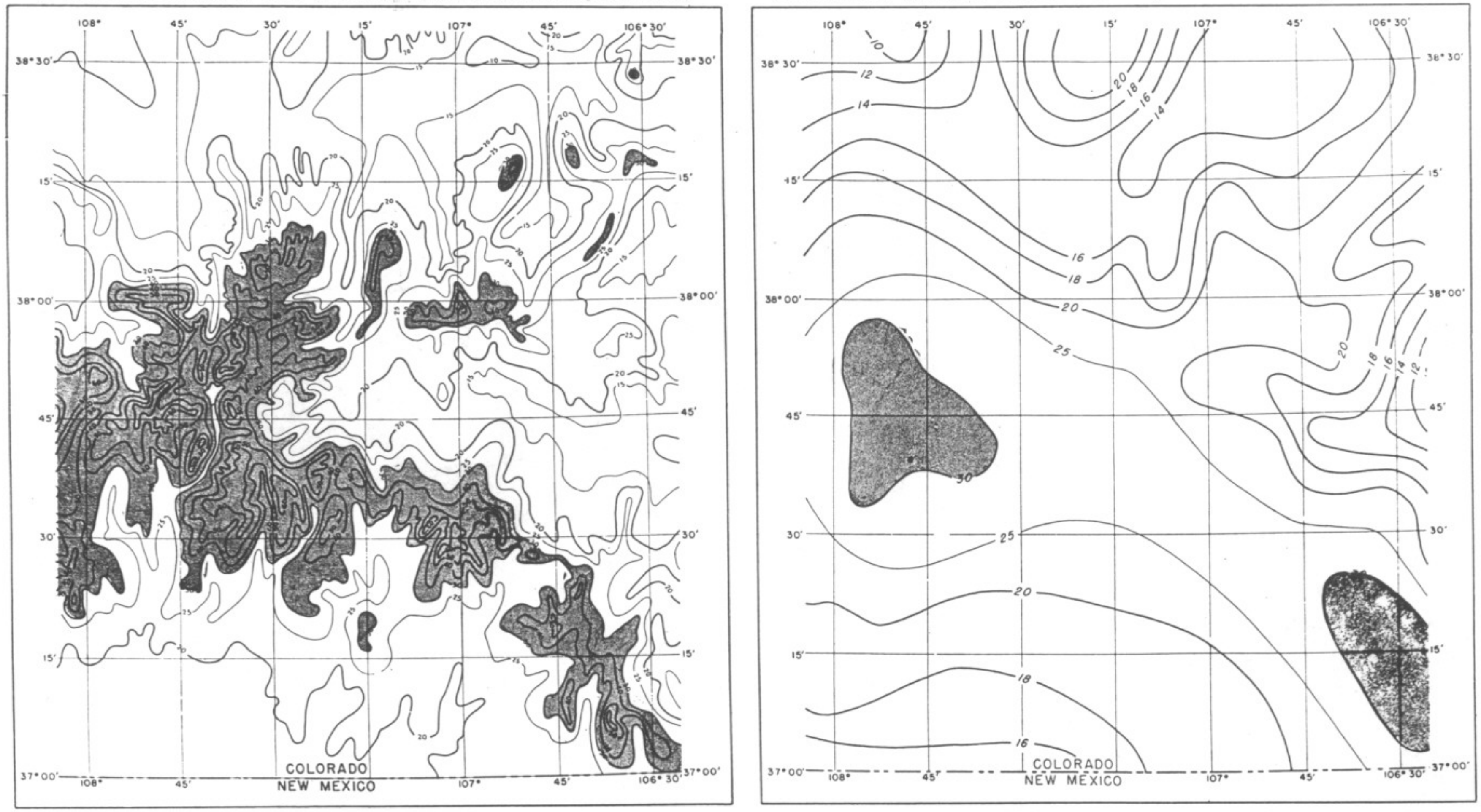
NORMAL ANNUAL PRECIPITATION FOR SOUTHWESTERN COLORADO

Based on adjusted climatological data and values computed by use of topographic parameters

(5-inch isohyetal intervals for values up to 30 inches; 10-inch intervals for greater values.)

Based on unadjusted climatological data
(From U. S. D. A., 1941 Yearbook, CLIMATE AND MAN.)

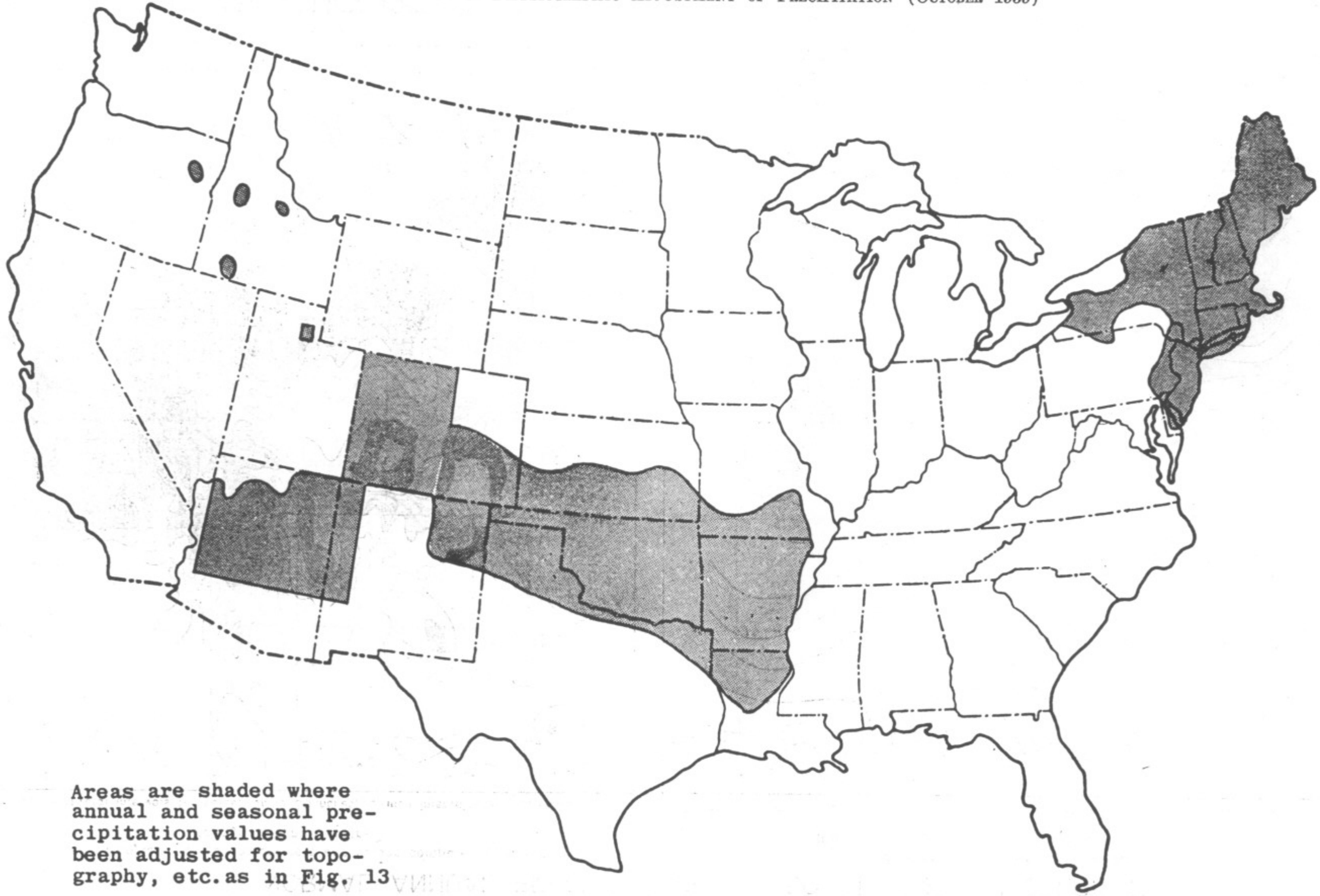
(2-inch isohyetal intervals for values up to 20 inches; 5-inch intervals for greater values.)



ADJUSTED (26 MILLION ACRE-FEET)

UNADJUSTED (20 MILLION ACRE-FEET)

FIGURE 14.—STATUS OF PHYSIOGRAPHIC ADJUSTMENT OF PRECIPITATION (OCTOBER 1959)



Areas are shaded where annual and seasonal precipitation values have been adjusted for topography, etc. as in Fig. 13

Figure 14 shows the areas where mean annual and seasonal rainfall patterns have been adjusted after analysis of topographic and meteorological effects. Extension of streamflow record by rainfall-runoff analysis has been done for only a few basins, on an experimental basis. Generalized estimates of probable maximum precipitation will shortly cover all of the contiguous United States, but for the best estimates specific basin studies are required. Most of these have been done on assignment from the Corps of Engineers. Rainfall intensity-frequency studies have moved forward rapidly in recent years but they still depend largely on the records at points. Intensity-frequency analysis of areal rainfall has had only a beginning, as is also true of drought studies.

How adequate are our rain gage networks? There is no simple answer because the estimate of adequacy must be referenced to a purpose, although all purposes involve the use and planning of area water resources or water-related projects.

Analysis of storm rainfall requires very dense networks. A gage for every square mile has been advocated for the analysis of thunderstorm rainfall. The required flash-flood warning network would approach this.

For general climatological purposes the need is much less. For its national (contiguous U.S.) climatological coverage the Weather Bureau's present plan is a representative network averaging 1 gage for 625 square miles—5,160 gages, of which 79 percent were in existence by June 1, 1959. Incidentally, 444 of the 1,091 sites still required are within uninhabited areas, indicating the need for unmanned equipment. Benchmark stations, where stations can be maintained for a long time without environmental change, are a smaller need numerically—but most important to the study of climatic trend. For a hydrological network, Linsley in his "Techniques for Surveying Surface-Water Resources" suggests (p. 28) that each study basin (preferably less than 500 square miles) should have—

* * * a first order hydrometeorological station and three or four precipitation stations within it.

or about one station each 100 square miles.

The "Report by the Presidential Advisory Committee on Water Resources Policy" recommended (p. 10):

About 5,000 additional stations, mostly precipitation, are needed and should be established during the next 5 years.

Hoyt and Langbein ("Water Facts for the Nation's Future," p. 44) report that:

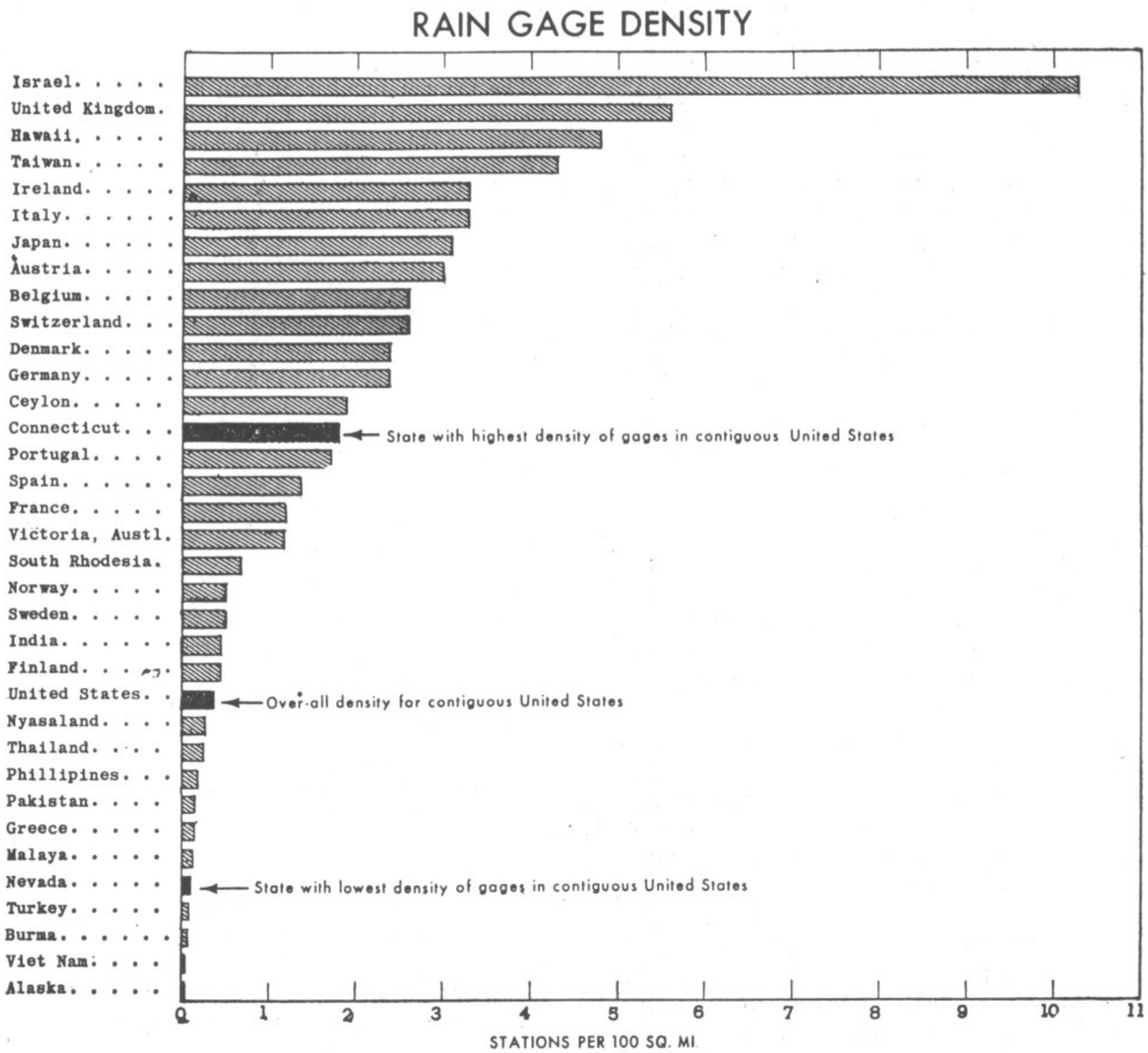
A check of 5,800 stream-gaging stations with drainage areas of 400 square miles or less showed that only 15 percent have a rain gage within or adjacent to the drainage area.

The present number of rain gages in the contiguous United States, for all purposes, is about 11,500—about 1 gage for an average of 270 square miles. The density varies from about 1 in 55 square miles in Connecticut to about 1 in 950 square miles in Nevada. It includes local networks, in cities and for special studies, of extreme density—one every few square miles; which means there are large areas devoid of rain gages. It is instructive and startling to compare our rain gage density with that of other countries, as is done in figure 15. We are far down the list.

Judging by the experience this figure shows, a twofold to threefold increase in our gage density should be planned. We should expect increases in technical skill that will make it possible to substitute synthesis and interpretation, and radar techniques, for many observations. But, on the other hand, it is extremely likely that increased needs will affect those technical advances. As water resources development increases, so do the operational requirements for observational data.

In addition, there is a requirement for further development and research in this field. The present-day rainfall gage, for example, is a very simple device. Basically, it is merely an open can into which the rain falls; the depth of accumulated rainfall is then measured with a stick. For purposes of recording rainfall intensity, the can may be placed on a scale which provides a continuous record of weight which is easily interpreted as depth of rainfall. It is known, however, that the accuracy of such gages is highly variable. The effect of wind may be to divert a substantial part of the rainfall which should fall into the gage, and it is conceivable that wind occurrence may even increase the catch above the true value. A considerable amount of research is needed to find an effective and yet relatively inexpensive gage which can be used to replace existing equipment and to fill the need for equipment at new stations. Actually, not one but several types of gages are necessary. The requirements are different where the gage may be observed daily in contrast to those remote locations which the observer can reach only once a month, or even less frequently. Automatic recording gages are necessary to secure information on rainfall intensity which is important to the design of spillways for water conservation projects, as well as to the many water

FIGURE 15



control structures, such as highway culverts, municipal drainage works, and flood control works.

In addition to a research program aimed at devising a satisfactory rain gage for the measurement of rainfall at a given point, we need to know more about the reliability of rain gages in terms of the rainfall over large areas. At the present time, a rain gage whose area is about one eighty-millionth part of a square mile must be assumed to represent the rainfall over areas as large as 250 square miles or more. Research projects involving networks of closely spaced gages would be useful in determining how rainfall varies within a storm and, consequently, how the catch of an individual rain gage is related to the average rainfall over the surrounding area. It is quite likely that the nature of this variation is different in different types of terrain and in different climatic regions. Therefore, several research sites appropriately scattered around the United States would be required.

FACT 10

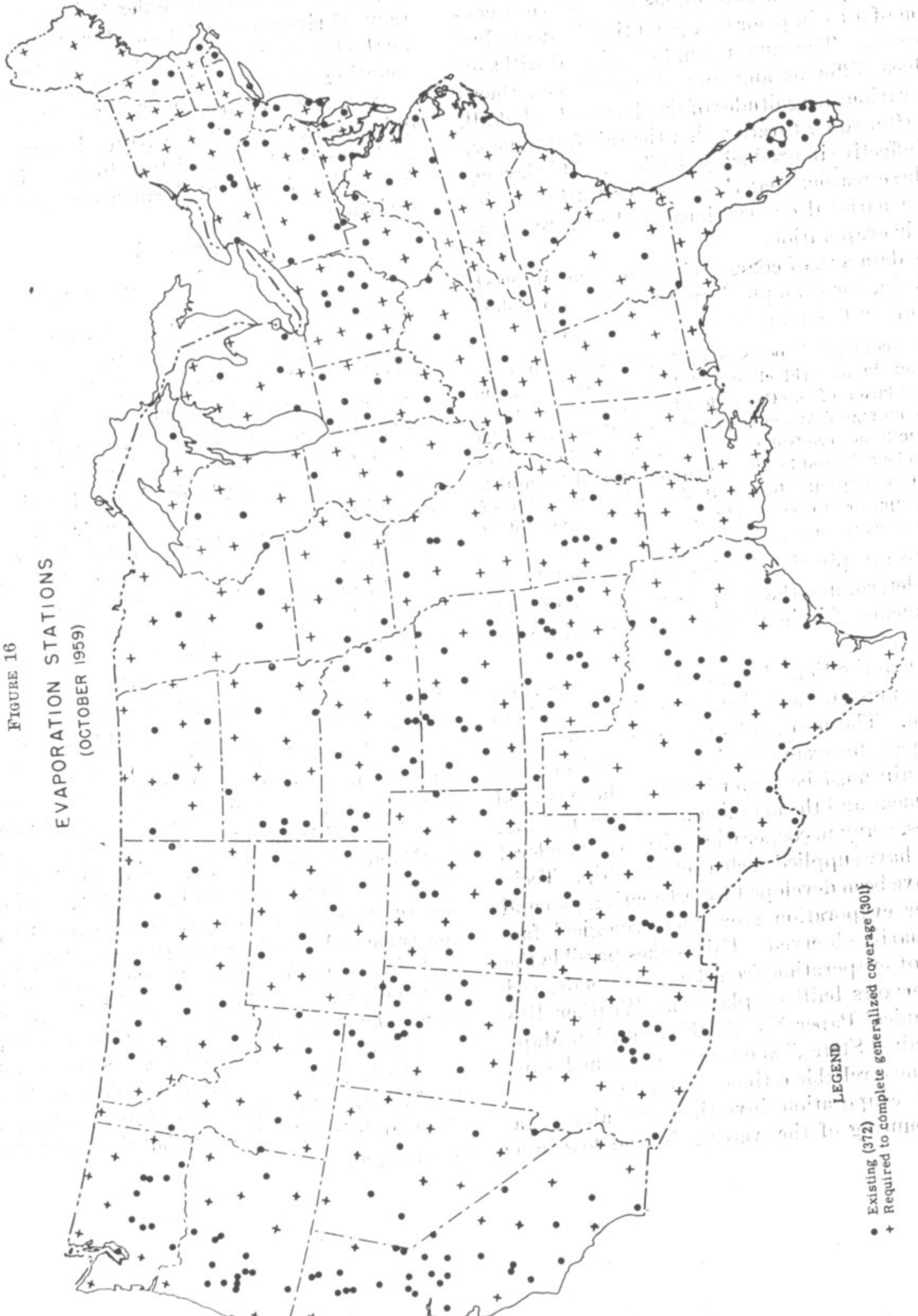
Evaporation limits both floods and potential reservoir storage

About two-thirds of the basic water supply provided by precipitation in the United States is lost through evaporation and transpiration. Together, they are called evapotranspiration, the process by which water is returned to the atmosphere from water surfaces, from soil, and through

FIGURE 16

EVAPORATION STATIONS

(OCTOBER 1959)



LEGEND

• Existing (372)

+ Required to complete generalized coverage (301) plantlife. It is a critical item in river forecasting because the antecedent combination of rainfall and evapotranspiration determines the moisture condition of a basin prior to a potential flood-producing storm. The same amount of rainfall will thus produce different amounts of runoff and, therefore, various magnitudes of flood or no flood at all. It is after soil saturation that the rainfall becomes most effective in producing the flood. It is largely for these reasons that the Weather Bureau maintains a national observational and research program in evaporation.

The data are, of course, of much wider interest. Langbein, for example, has shown (U.S. Geological Survey Circular 409, 1959, p. 4) that:

> * * * evaporation imposes a ceiling on potential river regulation in an arid climate * * *. Insofar as mainstem regulation of the Colorado River is concerned * * * there is no significant gain in net regulation between 29 and 78 million acre-feet of capacity. The gain in regulation to be achieved by increasing the present 29 million acre-feet of capacity to nearly 50 million acre-feet of capacity appears to be largely offset by a corresponding increase in evaporation.

Evapotranspiration is also the essential factor which determines the frequency and magnitude requirements of irrigation, both for planning and operation.

Any investigation of evaporation or evapotranspiration must, of necessity, be carried beyond observation. The means of observation—the evaporation pan, for example—is an artificial one. A relationship must be found between the observed measurement and the magnitude of the real thing.

Studies, many in cooperation with other Federal agencies, have supplied such a relationship. Techniques have been developed for estimating pan and free-water evaporation from meteorological factors ordinarily observed. This makes possible the estimate of evaporation from lakes or ponds, and from reservoirs built or planned. Weather Bureau Technical Paper No. 37, "Evaporation Maps for the United States," about to be published, supplies the most reliable estimates to date.

Current evaporation investigations aim at a daily accounting of the water gain and loss in a basin. The immediate purpose is to develop an improved soil moisture index to increase the accuracy of river forecasts; and the first tests of the method show such an increase. However, the accounting procedure also provides information on evapotranspiration and, therefore, irrigation requirements. And it can be used to compute the past record of soil moisture to provide the data for study of drought frequency or soil moisture variation.

NEED 7

Better evaporation data

The current evaporation network consists of about 370 stations. Figure 16 shows their distribution and also the 300 stations required to complete a generalized coverage. Greater concentrations of stations would be required for special studies of topographic effects, irrigation effects, etc. It should be emphasized, as it has for precipitation data, that while analysis, interpretation and synthesis of data extend the usefulness of present observations and bridge existing gaps—both increase of basic data and their analysis continue to be required. The potential improvements in accuracy and detail justify it.

The measurement pan itself should be reconsidered. Most widely used is the present Weather Bureau class A pan, an open pan 4 feet in diameter and 10 inches deep. It has been used for many years, but no really intensive research has ever been devoted to possible improvements in design. It is impossible to make an evaporation pan which is thermodynamically and aerodynamically similar to all lakes and reservoirs, and it is quite hopeless to expect that an evaporation pan will yield the same values of evaporation as might be expected to occur from the soil. The problem, then, is to design a pan whose characteristics are thoroughly known so that it is possible to calculate the adjustment of observed evaporation required to make it applicable to a given lake or soil area. The Weather Bureau is sponsoring a small amount of research in this direction, but the effort should be enlarged.

The evaporation maps for the United States which have just been prepared by the Weather Bureau were based on data from existing evaporation stations and on evaporation computed for Weather Bureau first order stations using meteorological observations. However, the evaporation computations were based on 10-year monthly averages of the meteorological factors. There would be considerable benefits if the evaporation were computed for each year of record for all the first order stations and other stations maintained by universities, States, and private interests making the necessary meteorological observations. Such long records would provide more reliable estimates of the variability and frequency distribution of the annual or seasonal evaporation. Through the use of high-speed computers, it would be feasible to compute the evaporation for these stations on a daily basis. The daily values could then be used for a variety of studies to define evapotranspiration and soil moisture variability and frequency. In conjunction with the basin accounting method previously described, complete basin histories could be provided for study.

NEED 8

Legislation authorizing Weather Bureau acceptance of State and other non-Federal funds

In stating the need for more observing stations for precipitation and evaporation, the support for such expansion was not discussed. By law, the Weather Bureau is directed to make—

> * * * such meteorological observations as may be necessary to establish and record the climatic conditions of the United States.

It is a national responsibility, and in exercising it the Weather Bureau must allocate its funds on a national basis, somehow assuring a nationwide coverage in the national interest, though it may be difficult to define. However, there are many State and local requirements for greater detail and density of observations. When these are the requirements of other Federal agencies, they transfer funds to the Weather Bureau which already has the facilities and know-how for the job. When a State, local, or private agency has the requirement, it cannot secure the same cooperation from the Weather Bureau because the Bureau lacks authorization to accept and use non-Federal funds in such work.

The Presidential Advisory Committee on Water Resources Policy, the Interagency Committee on Water Resources, the Pacific Southwest Interagency Committee, and the American Society of Civil Engineers have all recommended that the Weather Bureau be given the same authorization as the Geological Survey.

The statement of Harvey O. Banks, director of water resources, State of California, concerning Senate bill 3017 (85th Cong., 2d sess.), to the Committee on Interstate and Foreign Commerce, March 12, 1958, indicates the State attitude:

> The Weather Bureau, unlike certain other agencies of the Federal Government such as the Geological Survey, is not under present law permitted to accept funds either under a complete or partial support basis from non-Federal agencies. This condition suggests need for a change in the basic legislation under which the Weather Bureau operates. The close coordination and excellent results which may be obtained by cooperative endeavor are demonstrated by the long and successful history of the program between the various branches of the Geological Survey and the States in the fields of surface and ground water supply, water quality, and topographic mapping. The State of California through its department of water resources has been an active cooperator with the Geological Survey in these various fields of endeavor for many years.
>
> Meteorology and climatology are important aspects of the hydrologic cycle with which the California Department of Water Resources is vitally interested. As an agency of the Department of Commerce, it is the responsibility of the Weather Bureau to collect, analyze, and disseminate at Federal expense, meteorological data needed for activities in connection with interstate commerce and to establish and maintain an adequate basic network to meet its statutory requirements for weather forecasting and issuance of flood warnings.
>
> Adequate funds for the performance of these duties should continue to be allocated directly to the Weather Bureau by Congress in sufficient amounts that it may competently perform this function. However, in many areas, there is need to supplement the basic information now gathered in order that more detailed evaluation may be made of the nature and occurrence of water supplies. California is most vitally interested in the most efficient and complete control and utilization of its water resources to meet the needs of all beneficial uses.
>
> Therefore, it is the recommendation of the State of California that legislation be enacted by the Congress which would permit agreements permitting cooperative financing between the Weather Bureau and non-Federal agencies under which the trained personnel of the Weather Bureau might be assigned to these cooperative endeavors to obtain and develop information and to make analyses thereof, in addition to that gathered under the Bureau's present basic responsibilities. If this legislation is enacted, we expect to take advantage of it, by entering into such a cooperative agreement at an early date.

Need 9

Study of meteorological trends and cycles

All engineering design for water conservation is, of necessity, based on the experience of the past. A particular river basin has produced a certain quantity of water on the average during the years in which we have either estimated or observed flows. Reservoirs are designed to conserve this quantity of water. A very large and unknown factor is the possibility of climatic trend. Is weather actually a random occurrence so that the records of the past few years are reliable indicators of the weather and streamflow that can be expected in a similar period of the future? There have been studies, such as those by Hurst on the Nile River in Egypt ("Transactions ASCE," vol. 76, 1950), and by Leopold on the Colorado River (USGS Circular No. 410, 1959), which indicate that wet years tend to occur in groups, as do dry years—cases of persistence rather than randomness. And there is well-known geologic evidence that over very long periods of time (millions of years) there are major shifts in climate—from tropical to arctic and back again.

Little is known of the nature of these climatic trends or cycles. Forecasting weather even a few months ahead is now not possible, except as a climatological expectancy. Yet, if we may expect increased rainfall and, consequently, increased runoff, it would profoundly influence our planning, as would also the expectation of decreasing rainfall and runoff. The problem is really more complex than implied above since we are really concerned with more than a changing rainfall regime. Increasing temperature and, consequently, increasing evapotranspiration, for example, can reduce runoff as effectively as a decrease in rainfall. In fact, it is this combination which so effectively created the Dust Bowl years of the thirties.

Extensive research on the problem of climatic trend should be supported so that we can know, if possible, what to expect in the future. This may prove to be the most difficult project in the whole field of water resourecs. It will benefit from some aspects of the work being done on long-range forecasting, as well as information gained from satellite observations and other space investigations. Even spotting the short-term trend—the persistent period—would be invaluable for operation. Reservoirs such as Lake Mead retain water in storage for several years as a reserve against drought. If one could foresee the probable weather for 2 or 3 years in advance, the required reserve could be smaller when it is anticipated that future years will bring an abundant supply. If the outlook for the future shows a period of short supply, larger reserves would be maintained.

Need 10

More trained hydrologists and meteorologists

The Weather Bureau, in common with other Federal agencies, has found it extremely difficult to recruit young men or young women with college training in the field of water resources. It would be difficult, indeed, to staff a significant expansion in the Weather Bureau's hydrologic activities at this time without a substantial program of in-service training.

Primary sources for staff in the hydrologic work of the Weather Bureau should be graduates of university programs in meteorology or civil engineering. Undergraduate programs leading to a bachelor's degree provide little of the necessary specialization. In addition, there are altogether too few students aiming at a career in hydrology.

A survey of all the universities in the United States which train meteorologists shows only about 114 civilian meteorology graduates in the 1958–59 academic year. At least half of these were scheduled for induction into the Armed Forces. For the rest, the Weather Bureau must compete with other Government agencies, industry and universities; and within the Bureau, hydrology and hydrometeorology must compete with the present great demands for aviation forecasters, satellite researchers, etc. It should be added that almost no specialized training in hydrology is offered to university students in meteorology.

Civil engineering programs are also not meeting the hydrologic need. A survey by Prof. Arno T. Lenz, of the University of Wisconsin, showed about 5,000 graduates with a bachelor of science in civil engineering in 1958. However, about 40 percent of the engineering schools offered no basic course in hydrology. In the same year, there were 870 graduating with an advanced degree in civil engineering, but there are only 30 to 50 advanced degrees per year in the hydraulics option. The survey does not distinguish between hydraulics, which may cover a variety of engineering design problems, and hydrology, which is a relatively specialized field. It seems likely that substantially less than half of the students enrolled in the hydraulic option are majoring in hydrology. Thus, the output of students with specialized training in hydrology may be expected to be no more than 15 per year. Statistics are not available for the field of ground-water geology, but it is clear that the number of ground-water geologists graduated annually is very much smaller than that for hydrologists.

While it might be said that part of the difficulty lies in the fact that the universities fail to offer adequate programs in these areas, the basic problem seems to be that students do not exhibit a significant interest. Universities will normally adjust their programs to the needs and interests of their students. There is an urgent need for a public awakening to the fact that special training is desirable in the field of water resources, that there is a substantial need for young men and women to enter this field, and that the future offered to these young men and women is as favorable as in other branches of engineering or meteorology.